SSC San Diego Biennial Review 2003

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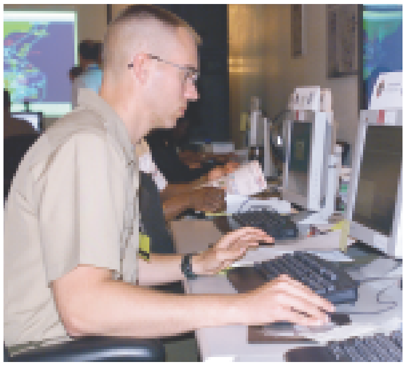

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Human Factors Engineering: An Enabler for Military Transformation Through Effective Integration of Technology and Personnel

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ABSTRACT

Transformation of the U.S. military requires new ways of defining both design and mission processes to improve warfighting performance and reduce system costs. New technologies engendered through the discipline of Human Factors Engineering at SSC San Diego enable warfighters to make more effective decisions in a timelier manner with fewer personnel. While the tradeoffs between new technologies and numbers of operators needed are complex, strong anecdotal evidence suggests that these manpower savings can be significant and have the potential to accelerate military transformation. The Human Factors Engineering community centered at SSC San Diego has documented and quantified the improved mission effectiveness of fewer warfighters operating enhanced combat systems. What is less well quantified—due to a number of institutional factors—is the true life-cycle cost of military operators. This paper discusses design factors that support reduced crew workload and factors that influence crew cost estimation and size. The conclusion is that although researchers at SSC San Diego have identified good candidate designs to support reduced crew workload, we cannot adequately trade off their cost with personnel costs until we can more accurately quantify these personnel costs.

The major institutions of American National Security were designed in a different era to meet different requirements. All of them must be transformed.

President George W. Bush
National Security Strategy of the United States
September 20, 2002 [1]

INTRODUCTION

As the United States' military transforms, warfighters are increasingly turning to technologists to solve operational challenges with technologies. A critical intersection between operational needs and technological solutions is in the multi-dimensional concept of command, control, communications, computers, intelligence, surveillance, and reconnaissance (C^4ISR).

Within the overarching discipline of C^4ISR, effective use of human–systems integration technologies enables warfighters to make better decisions. These technologies present exciting possibilities for enhancing warfighting effectiveness. These technologies assist in a number of ways by enabling (1) more effective decisions, (2) more timely decisions, and (3) an optimized number of personnel to operate systems.

Effective and timely decision-making has been observed and quantified in recent SSC San Diego projects such as the Multi-Modal Watchstation (MMWS) and the Knowledge Wall/Knowledge Web (K-Web). Software associated with decision-aiding and visualization reduces workload by augmenting or replacing manually intensive tasks.

The cost impact of technology to crew size is often obscured by the lack of one-to-one correspondence between a software technology unit cost and a resulting shipboard position change. Typically, the newer hardware technology is both more capable and cheaper than the old. Software development and testing becomes the chief cost driver. Cost tradeoffs between software and personnel could be a significant factor in determining feasibility and speed of technology transition to acquisition. For this reason, it is important to understand the manpower savings affected by various human–systems technologies as well as the concomitant manpower costs associated with continuing to use additional operators to employ legacy systems. Researchers at SSC San Diego have approximated manpower savings that can be achieved with emerging technology.

Research regarding the "true cost" of military personnel is less well quantified and therefore not well understood. However, this understanding is crucial if we are to transform the U.S. military and effectively use technology to enable manpower savings.

TRANSFORMATION: MAN AND MACHINE

Transforming the United States Military

Transformation of the military has been a strong theme of President George W. Bush since well before his term began in January 2001. Candidate Bush signaled the course for transformation in a speech in September 1999 [2] where he stated: "I know that transforming our military is a massive undertaking.…The real goal is to move beyond marginal improvements—to replace existing programs with new technologies and strategies...to use this window of opportunity to skip a generation of weapons systems." The Secretary of Defense 2002 *Annual Report to the President and the Congress* [3} highlights the importance of military transformation by noting that "Transformation lies at the heart of our efforts to reduce risk posed by future challenges."

Transforming the U.S. Navy

The Department of the Navy has invested substantial intellectual capital in coming to grips with how to transform the Navy and the Marine Corps. The Department of the Navy's plans for transformation were formally articulated in *The Naval Transformation Roadmap*, released in July 2002 [4]. This document set a clear course for transforming the Navy and the Marine Corps. The Chief of Naval Operations' (CNO's) vision for Navy Transformation, called *Sea Power 21*, was articulated in a series of articles beginning in October 2002 in the *U.S. Naval Institute Proceedings* [5].

Transformation involves changes in technology, policies, procedures, and designs that improve performance and save costs. Key tenets of *Sea Power 21* focus efforts such as those of the Human Factors Engineering (HFE) consortium at SSC San Diego and lead to the design of systems that enable significant performance gains with optimized personnel.

The Navy has increased efforts to capitalize on HFE research results. For example, in the Navy's *Fiscal Year 2003 N1 Playbook*, the Chief of Naval Personnel, Vice Admiral Norbert Ryan, notes "The design of new systems must include Sailors from the start"[6].

Recent fleet studies indicate that the Navy is firmly committed to efforts to reduce the crew size on ships. For example, in the case of the Navy's CVN 21 program, the Navy changed requirements dramatically in the fall of 2002, requiring the first ship of the new CVN 21 class to have a crew size that is 800 less than the current *Nimitz*-class carriers [7]. The success of such manpower reduction efforts is inextricably linked to successful HFE during design and development.

Efforts to use technology to reduce manning are not limited to new-construction ships. For example, the Naval Sea Systems Command has commissioned an exhaustive study to determine ways that technology can lead to reduced manpower requirements on the *Arleigh Burke* class destroyers. This study strongly advocated using groundbreaking Human Factors Engineering technologies while validating the need to reduce

manning on *all* Navy ships by noting that, since 1985, the Navy's Total Operating Budget has declined by approximately 40% and ship count by 45%; however, the Operations and Support (O&S) costs (consisting of personnel, maintenance, consumables, and sustaining support) have remained constant during this time. Personnel costs comprise over 50% of O&S costs, and these personnel costs have been growing more rapidly than other costs.

Thus, for both new-construction ships and existing ships, platforms, and command centers, there is an ongoing search by the Navy for improved human–systems design and technologies that enhance human performance. These initiatives have been formalized in three key enablers for naval transformation: *Sea Trial, Sea Warrior*, and *Sea Enterprise*.

Significantly, *Sea Enterprise* will use technology such as MMWS and K-Web to empower personnel to achieve warfighting effectiveness in the most cost-effective manner [5]. The complex missions undertaken by naval forces rarely enable manual processes to be replaced by automated ones with a "simple" substitution of technology for operators. Instead the process becomes "mixed," with human supervision of automated processes and human selection of automation levels. Cost comparisons of human versus machine must account for these mixed-initiative systems. HFE researchers at SSC San Diego have studied interaction with mixed-initiative systems and developed guidelines to support effective human–system interface design. A discussion of the design techniques used to support various levels of automation is important to understanding the relationship of complex system design and crew optimization.

HUMAN FACTORS ENGINEERING: ENHANCING OPERATOR PERFORMANCE

The Office of Naval Research has sponsored research in Human Factors Engineering concepts at SSC San Diego for several decades. Research conducted in the 1980s and 1990s supported the recent Multi-Modal Watchstation project and further progressed into two Future Naval Capability (FNC) projects supporting improved Land-Attack systems in Knowledge Superiority and Assurance and Capable Manpower [8]. Lessons learned can be summarized into three major factors: (1) human–computer interface (HCI) design, (2) information and software architecture supporting effective human–computer interaction, and (3) effective human factors design process [9].

There is a direct, but complex, causal link between effective HFE and personnel costs. Systems that are efficient and easier to operate require fewer personnel resources in all phases of training and operation. Poor design creates increased personnel burden and increased risk of mission failure, by inducing error and delays during peak mission task loads.

So what is "effective design," and how do we know when we achieve it? First, cognitive work domain and task analysis is a core part of the HFE methodology [10]. Effective design does not, by its nature, have to be complex or expensive. Sometimes simple solutions produce significant performance gains such as SSC San Diego research that led to a new method for selecting objects on a display by shifting more of the selection work from the human visual and motor systems to the computer [11]. The resulting changes improved performance for all types of input devices.

On a larger scale, human performance is transformed through redesign of the tactical HCI and user-interactive process [12]. Research results indicated significant improvements in situational awareness and task response for a typical Air Defense Warfare team. In both design cases listed above, it was most useful to start from a "blank sheet" of paper and define critical HFE requirements. These requirements and design attributes evolved through research and testing, and are related to a school of thought in HCI design termed as "Ecological Interface" design [13]. This type of design directly reflects and supports the mission process and visualization of that process. As illustrated in Figure 1, dynamic process visualization can be an important feature in supporting mission situation awareness. Tomahawk and Guns reflect step-wise processes while Air Defense is range-based and Engine Propulsion is time-based. Visualization supports important cognitive requirements related to user task roles; responsibilities; past, current, and future status.

Also, Human Factors Engineering researchers at SSC San Diego have identified a key requirement that software functions must support the construction of "mission task products—the quality of these products are key performance enablers. These requirements have been summarized recently in the SSC San Diego concept of a Goal-explicit Work Interface System (G-WIS) [14]. The G-WIS is a representative example of "Mission-Centered Computing" [15]. The G-WIS visualization does not presume an "office" Graphical User Interface (GUI) look or feel. HCI tools within that metaphor have been found sometimes to be impediments to the efficient performance required in fast-reaction weapons systems [16]. Performance-enabling properties of the G-WIS design approach have been found in fleet performance and usability testing [17]. The significant performance enabler is not the HCI look and feel but instead the quality of the task products and their contribution to the mission process. The degree of impact on manning and transformation is directly related to the product quality and availability across the gamut of tasks in varied mission domains.

The mission process and product requirements are captured through structured analysis of workflows and captured in HFE sequence diagrams and software Use Case and Activity Diagrams. Figure 2 presents a typical workflow analysis designed by HFE researchers at SSC San Diego. It shows the actions of human, system, and external entities by showing the path of information flow and processes. Links to display examples are shown in the diagram for viewing the content of decision aids at that point in the process flow. The workflows are also part of the Design Reference Missions, which contain the workload and mission demands required of the human–system combination. The workflow analysis also reveals mission process flaws that can be improved. This analysis may include a reduction of steps or methods that may be unnecessary artifacts from legacy systems. Understanding a mission process and improving it is critical to support crew optimization and naval transformation.

The complexity of measuring the impact of Human–System Integration (HSI) cuts across technology, system integration, and mission processes and protocols. As defined in a mixed-initiative system, automation is not a dichotomy existing in either an "off" or "on" state but is instead a continuum across multiple levels of human supervisory control. HFE researchers at SSC San Diego have shown conclusively that models cannot

FIGURE 1. Dynamic mission process visualization displays.

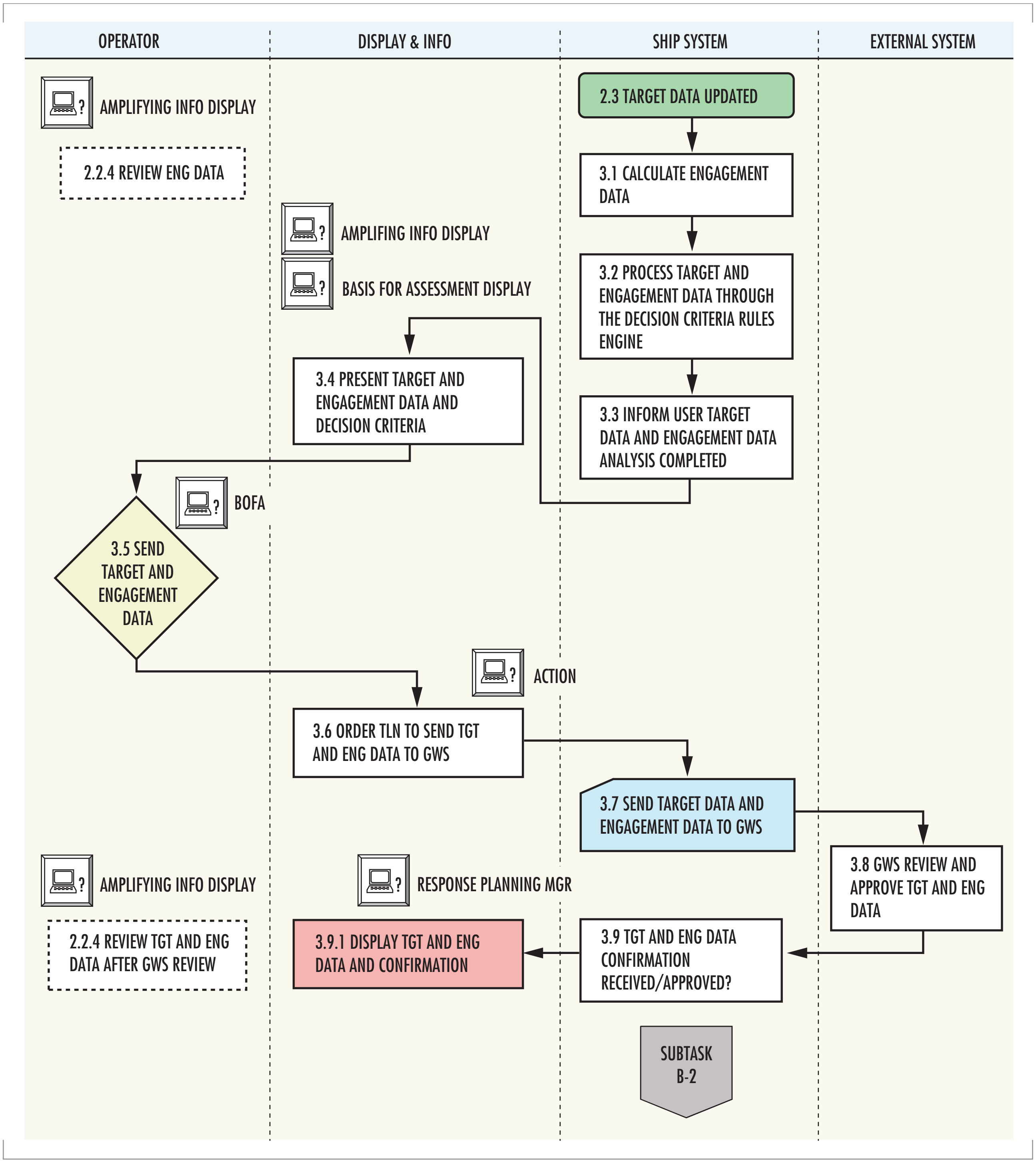

FIGURE 2. Example of workflow analysis linking workflow to decision support displays.

simply trade off automation for human processing one-to-one. Given the interaction between design and process factors, each factor must be included in models that estimate design impact on crew workload and crew size. Toward this end, the models that define cost variables impacting crew size and cost must be as accurate and objective as possible.

MANPOWER COST ANALYSIS: STILL AN IMPERFECT SCIENCE

Regardless of the effectiveness of various HCI technologies, cost weighs heavily on strategic decisions regarding technology purchase. Decisions will be made within the context of hardware, software, and personnel costs if these new systems are installed. These important trade-offs should be made in an objective manner with reliable metrics to guide the Services toward the correct decisions.

Strong anecdotal evidence suggests that the metrics used to quantify the cost of a warfighter provide only rough approximations of costs. While there are many reasons for this, an exhaustive study by the Center for Naval Analysis (CNA) concluded that, within the Navy, there are insufficient organizational imperatives to mate technology and manpower decisions [18].

For example, the workyear rates promulgated to determine Future Year Defense Plan (FYDP) requirements for manpower provide a single rate for officers and a single rate for enlisted personnel, making no distinction among paygrades.* This averaging of rates skews any attempt to derive objective data regarding personnel costs. This may tend to make legacy systems appear to be as cost-effective as new human–systems technologies by obscuring the fact that more junior, less-experienced personnel can be trained on new systems with improved HSI versus legacy systems that required more experienced operators.

While Navy manpower models purport to include all costs of manpower (and they do a reasonable job of that), in reality they quantify that which is readily quantifiable while omitting some important costs that do impact the "life-cycle cost" of personnel. For example, the Navy "model" does not readily factor-in recruiting or training costs, often obscuring the extremely long pipeline training for some personnel such as aviators and nuclear-trained officers. The model is also not easily adapted to factor-in the extraordinary costs of war, including special pay for being in a war zone. Additionally, there is no way to factor-in the vast infrastructure of Family Support Centers, Child Development Centers, and similar family support entities.

In short, while manpower analysts have done a credible job of deriving a first-order approximation of Navy manpower costs, institutional factors auger against their refining these metrics to make it a precise instrument to enable objective manpower–technology trade-offs. Unless or until these models are refined, manpower cost analysis will remain an imperfect science.

CONCLUSIONS AND THE IMPERATIVES: FURTHER RESEARCH

Military transformation will continue to demand that technology replace manpower on platforms, systems, and command centers. HCI technology like MMWS and K-Web developed at SSC San Diego can enable mission processes to be completed in a timely and effective manner with optimized numbers of personnel. Quite often, the roles of warfighters will need to shift toward supervisory control of multiple mission processes versus manual control of a single mission process. Software systems must be designed to produce high-quality mission products enabling effective warfighting with fewer personnel. HFE researchers at SSC San Diego

*Chief of Naval Operations (N10) directive dated 22 January 2003, Serial N1021/01. In January 2003, the FY 03 "cost" for an officer (O-1 to O-10) was $100,106, and the "cost" for a sailor (E-1 to E-9) was $49,619.

have shown that, in many cases, costs for duplicate functionality can be shared across systems, thereby reducing the cost of automation or decision support. The costs of better automation and high-quality software mission products must be compared to the "true" cost of personnel.

Directly comparing the manpower costs to systems development and maintenance costs does not always tell the entire story, nor does it necessarily provide a complete and objective analysis. The quality and reliability of performance, coupled with the speed, accuracy, and efficiency of decision-making ultimately impact the mission performance of these operators. Clearly, this is an area requiring more research and modeling to determine the viability of coordinating the optimal mix of smarter systems and crew size. This area also demands research that will lead to more effectively defining the "true cost" of an officer or an enlisted person on Navy ships, and this research can reduce the risk that "manpower-heavy" Navy platforms will become unaffordable, inhibiting Department of the Navy transformational initiatives and reducing the contribution that the Navy can make to the National Security of the United States.

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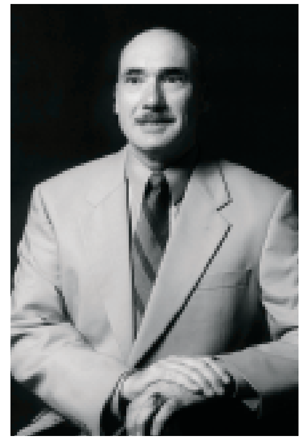

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Interactive Multisensor Analysis Training (IMAT)

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ABSTRACT

The objective of the Interactive Multisensor Analysis Training (IMAT) project is to better train operational users of undersea-warfare sensor systems. The effort has focused on training at all levels from initial training ashore through team, platform, and collective training at-sea, at all skill levels from apprentice sensor operators to senior tactical commanders. Operators and tacticians at all levels need a deep and scientifically accurate, but not necessarily formal understanding of the physical principles that underlie tactical use of sensor systems. IMAT systems use scientific visualizations, three-dimensional graphics, and animations to illustrate complex physical interactions in mission-relevant contexts. Instruction concepts include radiated acoustic characteristics, propagation in range-dependent environments, and sensor properties. Training systems provide exploratory environments in which operators and tacticians can examine the effects of change in any of the variables involved in the end-to-end sequence of emission, transmission, reflection, and detection. Sensor settings, environmental conditions, and target characteristics can all be modified through a "what-if" simulation approach. These technologies have been applied effectively in basic and advanced sensor operations/employment courses, in individual and team training simulators, and in onboard training.

INTRODUCTION

Tactical sensor employment is hard to learn and hard to train. Extensive knowledge and substantial inferential capability are required to interpret sensor data, generate hypotheses about their meaning, and propose courses of action. In the real world, the proper interpretation and use of sensor data are among the most difficult tasks in many science-based fields of endeavor. Examples include use of geological data in oil exploration, imagery and biochemical test results in medical diagnosis, spectrographic and bio-chemical data in forensic analysis, and electromagnetic, electro-optic, and acoustic signal analysis in naval warfare. All of these tasks require deep understanding of the physical properties being sensed, the operation and limitations of sensors, and the environmental or real-world interactions that affect data observation and interpretation. In most warfare applications, these tasks are even more difficult because intelligent opponents seek to avoid detection, confuse identification, and gain tactical advantage by employing intelligent countermeasures or unconventional maneuvers.

In many fields, graduate-level degrees and many years of experience are required to develop the necessary skills for reasoning in dynamic, highly variable, and ambiguous situations. In contrast, junior enlisted operators in the Navy often perform sensor employment tasks that are essential to the tactical outcome of combat events. Most operators are high-school graduates with very limited formal education in physics and engineering, and with no experience in real-world operations with non-cooperative opponents.

In antisubmarine warfare (ASW), the training challenges are especially formidable. Foreign nuclear submarine technology continues to improve, and advanced submarines continue to be built and delivered. At the same time, the proliferation of improved diesel-submarine technology to many Third World nations requires that ASW forces adapt to those threats as well. Since ASW is no longer only an open-ocean, deep-water enterprise, operations must now be conducted in the vastly different littoral regions. Also, in the past, extensive opportunistic practice occurred in the normal course of submarine operations. Today, because contact opportunities with capable potential adversaries are relatively infrequent, new training is necessary to develop the knowledge required to deal with quieter targets in more complex environments, and more practice opportunities are necessary to develop advanced sensor employment and tactical skills that were previously learned on the job.

THE IMAT PROGRAM

The Interactive Multisensor Analysis Training (IMAT) program is providing training and performance support systems designed to make difficult scientific and technical concepts comprehensible to the operational users of advanced sensor systems. IMAT goals include (1) developing systems that integrate computer models of physical phenomena with scientific visualization technologies to demonstrate the interactive relationships of threat, environment, and sensor for operator training, and interactions of multiple sensor systems for tactician training; (2) developing training and performance support systems using modeling and visualization technologies; (3) integrating curricula to provide training on high-level sensor operation and tactical planning skills; and (4) developing modeling and visualization tools for use at sea, both for training and as tactical decision aids.

Several IMAT visualization systems have been developed. A large-scale version of the system uses high-end workstations with special-purpose parallel processing to provide very rapid sensor performance visualization. This version is used primarily as a tool for exploring tactical implications of sensor employment, and also as an instructor tool in classroom settings. This system is also the basis for new-technology multi-operator submarine sonar training systems, and for deployed training and tactical visualization on submarines and surface ships. Personal computer (PC) IMAT is a laptop-based system that can be used both tactically and as an instructional tool. The system allows individual users to make timely sensor performance predictions based on available environmental data, and it allows students to review, reinforce, and explore, at their own pace, complex concepts involved in ASW. The system has recently been extended to provide shared operational information over afloat networks for collaborative tactical planning, multi-platform battle-group-level situation assessment and analysis, and distributed training.

This paper briefly describes how basic concepts are taught using IMAT in apprentice sonar-operator courses. These basic concepts include fundamentals of acoustics, acoustic properties of targets, properties of sensors, and environmental effects on propagation. The approaches for simulation-based sonar training and at-sea training at the ship and battle-group levels are also discussed.

Acoustics

Basic concepts of sound and wave theory, such as sound pressure, frequency, wavelength, velocity, and amplitude are initially introduced by using visualizations. The intent is to give qualitative explanations of the underlying phenomena. From the beginning, these topics are taught in a "real-world" context by relating them to properties of submarines relevant to the tasks of detection, localization, and classification.

The submarine display (Figure 1) provides animated visualizations of the internal components of a submarine. The display is linked to recordings of actual acoustic data. Selecting a motor, pump, or other object will display a description and will highlight frequency lines associated with the component on the sonogram in the bottom part of the display. This enables the student to better understand how complex assemblies work, why they generate certain signals, and how signals relate to operating mode and speed. Selectable components include examples of diesel

engines, turbines, reduction gears, pumps, propellers, motors, generators, compressors, and blowers. In addition, a high-fidelity acoustic simulator is also included. Most parameters that control the simulation can be varied and explored for instructional purposes.

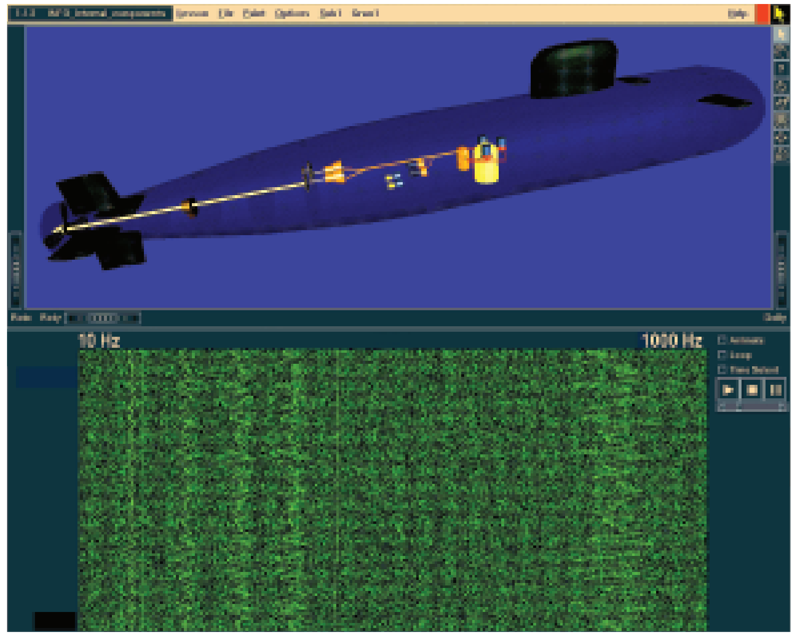

FIGURE 1. Power-train components related to acoustic signature.

Sensors

The properties and functions of acoustic sensors are explained in the context of detection and localization, that is, how the sensitivity of sensors can be directed so as to increase signal relative to noise, and so as to provide directional information. Again, interactive animations are used to explain underlying concepts. For example, for principles of beamforming using a phased array, a three-dimensional rendered view of isosensitivity was provided for a given combination of array elements, inter-element spacing, and phase delays. The system can accommodate multi-aperture and other (e.g., nonlinear) array geometries. The user can vary all parameters in these displays in order to investigate beam width and directivity as a function of array design and employment.

Environment

A third part of the conceptual foundation for sensor employment involves environmental effects on sound transmission in the ocean. IMAT includes an interactive modeling facility to help students explore and understand transmission loss. Since transmission loss is affected by spreading, absorption by the bottom, and scattering at the bottom and surface, all these factors are controllable in the interactive displays. IMAT includes extensive environmental models, including Parabolic Equation (PE) and Gaussian Ray Bundle (GRAB) range-dependent propagation loss models, and databases on bathythermography, bottom absorption, and other oceanographic data, all approved by the Oceanographer of the Navy. With these modules, a user can select any geographic location and time of year, extract, view, enter, and/or modify environmental data (such as sound speed, bottom loss or reflectivity), enter/modify source and target depths and frequency of interest, and then model propagation loss as a function of depth, distance, and azimuth from a sensor or threat. Figure 2 shows an example full-field plot, with the bottom panel showing transmission loss over range at the indicated sensor depth. At a very early point in training, students can be introduced to the high degree of variability in environmental features and to its importance in sensor employment.

Many other interactive displays for conceptual understanding are available in IMAT and PC-IMAT, including properties of other sensors such

as sonobuoys, electro-magnetic and electro-optical sensor systems, and basic and advanced concepts for active systems, including multistatics.

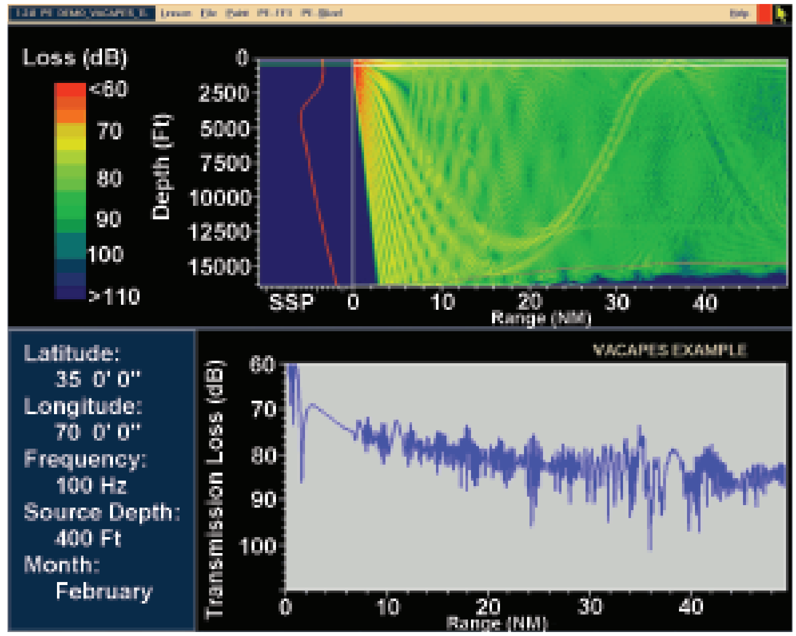

FIGURE 2. Full-field transmission loss plot.

TRAINING EFFECTIVENESS

IMAT shore-school products have transitioned from research and development and are now used in over 20 apprentice-to-advanced courses in the submarine, surface, air, and meteorological/oceanographic communities. Evaluations of training effectiveness in shore schools indicate that IMAT is among the most successful training technologies ever introduced in the Navy. The Naval Studies Board of the National Academy of Sciences [1] noted:

- IMAT students outperform students in conventional instruction, and, in many cases, score higher than qualified fleet personnel with 3 to 10 years experience. Evaluations consistently show gains of two to three standard deviations on comprehension, reasoning, and problem-solving tasks. Overall, the IMAT approach is much more effective than conventional lecture instruction or new technologies such as interactive video or computer-based training.
- Instructors report that IMAT increases their ability to teach difficult topics, respond to student questions, and reinforce critical principles.
- IMAT students score higher on attitude scales measuring attention, relevance, confidence, and satisfaction than students in standard Navy classrooms or students in specially designed individualized computer-based training.
- IMAT development costs for initial courses are equivalent to or less than conventional courses and less expensive than other new-technology courses. Subsequent development of related training is up to 90% less expensive.

The Commander, Naval Education and Training Command and the Office of the Chief of Naval Operations (OPNAV) sponsors are currently completing implementations throughout the submarine and air ASW training pipelines and are planning for expansion of IMAT training in the surface community.

TEAM TRAINING FOR TACTICAL SENSOR EMPLOYMENT

IMAT technologies support more advanced team- and platform-level training in tactical employment of sensors and tactical use of the environment. A new-technology submarine sonar employment trainer (SET),

which uses IMAT visualizations, is now being delivered to the Naval Submarine School. The primary functions of the SET are to provide instructor-controlled, scenario-based training with "what-if" capabilities. This training will support development of reasoning concerning sonar systems employment and tactics by exposing trainees to experiences that might only have been encountered opportunistically during mission deployments. These scenarios will allow sonar operators, sonar supervisors, and sonar coordinators to work as if deployed, and to explore alternative courses of action to maximize learning from a variety of operational situations and environmental conditions.

This work has also transitioned to the Submarine Multi-Mission Team Trainer, Phase 3 (SMMTT3). The SMMTT is a full combat systems team trainer for the sonar, fire-control, and combat-center teams. Acquisition funding began in fiscal year (FY) 02 and is programmed through FY 06 for systems at all six submarine training facilities.

AT-SEA PERFORMANCE SUPPORT

More recent work has extended IMAT technologies to onboard mission support for ASW operations. For more complicated tactical analyses, precise data are necessary for entry into sensor-performance predictions. Therefore, extensive databases on threat characteristics and sensor sensitivity/directivity are included. These, together with the high-resolution environmental databases described previously, allow users to do exercise and mission planning, execution monitoring, and reconstruction. IMAT systems provide visualization tools for both monitoring of a current tactical situation, as well as for investigating "what if" suppositions. IMAT/PC-IMAT systems are approved as Tactical Decision Aids on all U.S. submarines and surface combatants. IMAT visualizations are now part of the submarine acoustic rapid commercial-off-the-shelf (COTS) insertion (ARCI) combat systems acquisition, and are Program of Record Tactical Decision Aids for submarine, surface-ship, and Integrated Undersea Surveillance System (IUSS) applications.

The PC-IMAT Destroyer Squadron (DESRON) Support System has recently been developed to provide battle-group-level planning and monitoring tools. Figure 3 shows the installation aboard USS *Kitty Hawk* (CV 63). The system is also capable of interacting over secure networks with other PC-IMAT systems to share data and to provide a common tactical picture. Further work is currently integrating the system with other ASW tactical systems to develop the Common Undersea Picture. The overall program is developing battle-group- and theater-level visualization systems to support multiplatform ASW tactical planning, tactical support, and reconstruction/feedback.

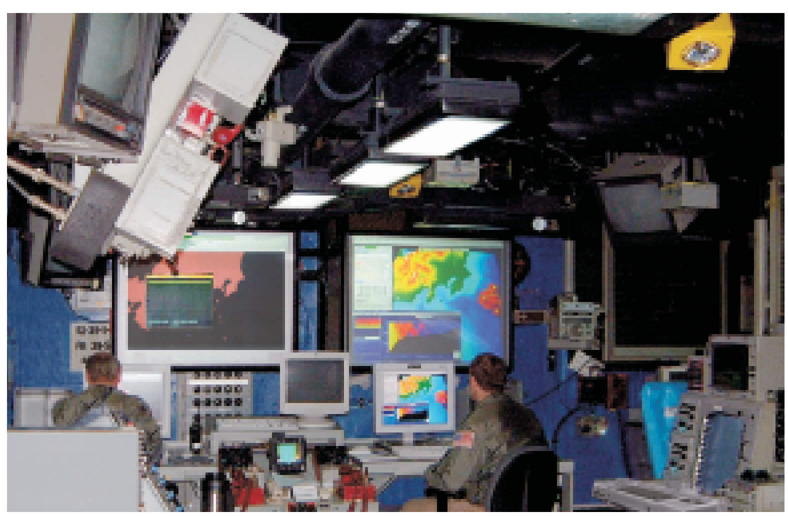

FIGURE 3. PC-IMAT DESRON Support System, USS *Kitty Hawk*.

IMAT FLEET TRAINING

Since 1997, the IMAT program has also been developing new approaches to waterfront and onboard training. The strategy has been to provide extensive pre-exercise training to the sonar and combat teams, during which the upcoming exercise is used as a basis for tactical planning. Then, IMAT project personnel provide at-sea training and support during the exercise and also provide reconstructions and lessons learned. To date, this effort has supported 10 major carrier battle-group workup, exercise, and deployment cycles. In 2002, the Commander, Pacific Fleet (COMPACFLT) and Fleet Forces Command institutionalized this effort as a Fleet Training Program of Record. IMAT fleet training is a central part of the COMPACFLT initiative to re-invigorate ASW proficiency.

CONCLUSION

Today, IMAT is a unique set of efforts that cross sponsor, mission, platform, and sensor boundaries. IMAT is truly interdisciplinary, including work in physical acoustics; oceanography; electromagnetics and electro-optics; modeling and simulation; training and information management technologies; sensors, processors, and display technologies; tactics development and analysis; environmental data collection and distribution; and command, control, communications, computers, and intelligence (C^4I).

The IMAT vision is to integrate training, operational preparation, tactical execution, and post-mission analysis into a seamless support system for developing and maintaining mission-related critical skills. In many ways, IMAT is a prototype for future human performance support systems that transcend traditional shore school and course structures to span career-long skill development from apprentice to master levels, across missions, platforms, and communities.

ACKNOWLEDGMENTS

The IMAT program is a joint effort of SSC San Diego and the Naval Surface Warfare Center, Carderock Division (NSWCCD), supported by several contractor companies. Over 50 people have worked on the IMAT effort, and the authors would like to thank, in particular, Bill Beatty and Rich Loeffler (NSWCCD); Kent Allen and Dan Lawrence (Anteon Corporation); and Eleanor Holmes, Jeff Raver, and Rick Krutz (Presearch, Inc.) for their contributions to the program. Portions of the work described in this paper are supported by the Capable Manpower Future Naval Capability program in the Office of Naval Research, Code 34.

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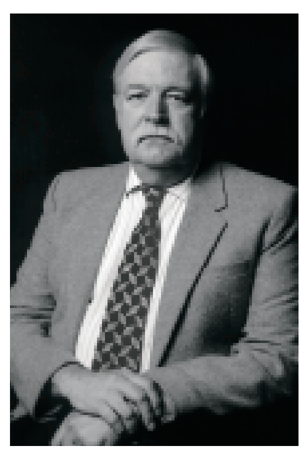

U.S. Central Command Deployable Headquarters

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ABSTRACT

SSC San Diego participated in the rapid acquisition build of the U.S. Central Command Deployable Headquarters (CDHQ) for deployment to Qatar in the Persian Gulf. Originally planned as an Advanced Concept Technology Demonstration to be built over a 3-year period, the CDHQ was produced in less than 10 months by a unified team made up from multiple services, civilian agencies, and private companies. The CDHQ provides a deployable headquarters to the joint service on-scene commander. Included in the CDHQ are state-of-the-art communications and a command, control, communications, computers, and intelligence (C^4I) application computing infrastructure. This paper describes SSC San Diego efforts as part of the CDHQ team and the lessons learned in its production and delivery.

INTRODUCTION

The U.S. Central Command Deployable Headquarters (CDHQ), now referred to as Command Headquarters Forward or CHF, was a rapid acquisition build for deployment to Qatar in the Persian Gulf. The CDHQ provides a deployable headquarters to the joint service on-scene commander. Included in the CDHQ are state-of-the-art communications and a command, control, communications, computers, and intelligence (C^4I) application computing infrastructure. The CDHQ was produced in less than 10 months by a unified team made up from multiple services, civilian agencies, and companies. SSC San Diego provided leadership and engineering for the system architecture, systems design, applications integration, integrated logistics, and safety, as well as communications and security for the CDHQ. When completed, the CDHQ provided a deployable headquarters for over 250 warfighters. Deployed to Qatar in the Persian Gulf, the first major test of CDHQ was during the Internal Look '03 exercise in December 2002, followed by Operation Iraqi Freedom and continuing operations.

The CDHQ was a large-scale systems development and integration effort performed under highly constrained, poorly defined conditions. In this paper, we describe SSC San Diego's efforts as part of the CDHQ team and the lessons learned in the CDHQ's production and delivery.

BACKGROUND

Prior to 11 September 2001, planning had begun for the Deployable Headquarters (DHQ) Advanced Concept Technology Demonstration (ACTD). The Joint Precision Strike Demonstration (JPSD) Project Office and SSC San Diego proposed a 3-year development program to produce the DHQ. After 11 September, the task changed. U.S. Central Command needed a forward command center capability within months. The ACTD became a rapid acquisition program of the new U.S. Central Command Deployable Headquarters (CDHQ) for the Commander, General Tommy Franks. JPSD was chosen as the program manager and SSC San Diego accepted the task to lead a government technology team to design and build the CDHQ. On 25 September 2001, an ad hoc team convened in Washington, D.C. with no plans for funding, specifications, or design. JPSD issued a contract to their prime contractor, Raytheon, who subcontracted to General Dynamics and others to deliver the CDHQ. An interim design process put the program in place by October and a design concept was delivered on 1 November 2001, about the time the first funding was released.

The highest level requirement was often summarized by U.S. Central Command (CENTCOM) as "We want the C4I capability we have at USCENTCOM, MacDill AFB, put in hard-sided shelters and made ready for the field." The CDHQ team determined the overarching requirements, either specified or derived from good engineering as follows. The CDHQ:

1. Shall be modular, scalable, tailorable, field maintainable, and field supportable.
2. Shall be deployable via air (C-17 or C-5 aircraft, but not C-130s) or sea, and ground transportable to the operational site.
3. Shall be interoperable, within security limitations, between joint and coalition government organizations, and non-government organizations.
4. Shall provide approximately 250 watch positions as specified at the CENTCOM J-code, watch position description, and by shelter type and seating-level charts.
5. Shall provide the C4I applications capability available at CENTCOM, plus collaboration capabilities.
6. Shall provide all communications through the Joint Communications Support Element (JCSE), the designated communications provider to CENTCOM in the field.
7. Shall provide some level of chemical and biological protection.
8. Shall be robust and designed for future growth and technology insertion.
9. Shall be able to run off of 50-Hz or 60-Hz power from either commercial power or generators.

Between December and August, the team designed, fabricated, tested, and delivered the deployable headquarters to CENTCOM from the Raytheon facility in Florida. The CDHQ development site was composed of an outer Secret-level compound and an inner sensitive compartmented information facility (SCIF), or Top Secret-level compound. Standard 16-person shelters were designated for a specified J-Code (J2, J3, J4, J5, and J6) as shown in Figure 1, a specific command function (i.e., Joint Operations Center [as shown in Figure 2], Command Briefing Room, Commander in Chief and Deputy Commander in Chief shelters [now Commander and Deputy Commander], war room, Theatre Communications Control Center), a support function (six server shelters supporting the four networks, NIPRNET [unclassified but sensitive Internet protocol network], Combined Enterprise Regional Information Exchange System [CENTRIXS] coalition network, SIPRNET [secret Internet protocol network], and J2 JWICS Top Secret network), or storage.

FIGURE 1. Interior of a standard 16-person shelter.

DESIGN APPROACH

The CDHQ was developed under extreme conditions. This section examines best systems engineering practices under these conditions. The team's focus was on risk reduction, time-to-product, and quality of product. Representative issues and decisions are discussed.

Refinement of Requirements

The CDHQ program lacked well-defined requirements, complicated by limited access to CENTCOM personnel and facilities because of Operation Enduring Freedom, the war in Afghanistan. Requirements were often given by personnel that were several layers removed from the operational and support personnel (both military and contractors). Specification of requirements at the level needed for a complete design were lacking, so the team proceeded based on best engineering processes and approaches that left the maximum dynamics in the system for future changes.

FIGURE 2. Joint Operations Center shown during first operational use.

Design Approach: Using the team's past experience and professional contacts, material received from CENTCOM was consolidated and examined, and a plan for a generic, sustainable, and survivable capability was developed. When presenting various design approaches and procurements to the customer, we would sometimes get back information such as "we don't use those routers, Cisco® is what we are trained for," "we don't use that software version, we use different versions," and "we can't use that equipment because we have found that is not field maintainable." Complications arose in that the J2 and J6 communications and applications requirements were quite different, and there were nuances to the four networks we needed to support. Eventually, we achieved a compromise between what the user wanted and what we were able to deliver in the time given.

Reduce Project Complexity and Time-to-Build

The level of complexity of this project and the ambitious delivery schedule meant we had to use some best practice concepts to transform our generic capability into a delivered system that would support the warfighter. Time-to-build was hampered by long lead-time items and the large number of hardware pieces involved, complicated by the incremental funding from the government.

Design Approach: To reduce time-to-build, we divided the project into several parallel efforts. We limited our hardware platforms to only a few hardware types to minimize the integration problem. By choosing modular components and following standards, we also simplified the work. For example, needing to reduce complexity, only the CUSeeMe™ Servers and NetMeeting® clients of the Department of Defense (DoD) Collaboration Toolset (DCTS) were included. The CDHQ delivery schedule was created and the longest lead times examined to determine the best use of parallel efforts (e.g., establishment of two shelter refurbish and modification sites and multiple cable production sites) and schedule purchases. Initial purchases of long lead-time items, mostly hardware such as computers, had to be made before full knowledge of requirements and user preferences were known.

Increase CDHQ Field Robustness, Maintainability, and Supportability

The level of robustness, maintainability, and supportability while fielded needed to be better than that at CENTCOM. In the communications and

applications areas, this was because of the lack of specific vendors and parts expected in the CENTCOM area of responsibility. Additional dynamics were required; for example, users needed to be able to leave one shelter with a laptop, move to another shelter, and continue to work. There was little or no time for the CENTCOM team to learn new systems.

Design Approach: These goals were met by use of modularity, redundancy, dynamics, standards, and commonality wherever possible. Shelters were designed to be modular so that an application type shelter could be exchanged for another application type shelter if required. Redundancy was built into the systems; for example, both primary and secondary applications and communications servers, switches, and routers were used with fail-over. High-availability components were used where possible.

Simplify Security Requirements and Documentation

Simplifying security requirements and documentation is crucial to the delivery of any major product. Security must be considered from the beginning.

Design Approach: Because the networks and computers were to be distributed throughout the compound, we decided to use gigabit fiber to deliver network connectivity to each shelter. By putting all data and multimedia communications over fiber, cross-talk issues were eliminated. CENTCOM required that network cables be color-coded by classification to help ensure proper connection of networks. We also decided that we would stream all data over Internet protocol (IP). All transmitting antennas were placed on the outside of the compound for TEMPEST (Transient Electromagnetic Pulse Emanation Standard) reasons. Security expertise was brought in early to support development decisions, address standards, and develop the required documentation. Early decisions greatly affect the amount of rework and time-to-signoff for acceptance.

Develop CDHQ Development Site and CDHQ Field Site Requirements

A site layout was needed to meet the communications, power and grounding, shelter staging dynamics, and security requirements to establish the temporary SCIF at the development site and to support the field deployment site(s).

Design Approach: A notional site layout was designed and used for development because the actual initial site was unknown. The layout included approaches that were dynamic where possible, such as standard power and tactical fiber-optic cable lengths for the site.

Develop Shelter Requirements

The shelters were standard military (ISO, NAVAIR, and Modular Extendable Rigid Wall Shelters [MERWS]) honeycombed aluminum shelters that were government-furnished equipment (GFE) procurements. These shelters had to be retrofitted to support the CDHQ because a clean cable plant and support for equipment racks were required for safety reasons. Maximum weight requirements for the shelters also had to be met. To make them rapidly deployable, each shelter had either racks or transit cases containing the communications gear, uninterruptible power supplies, and cable plants.

Design Approach: The plan was to make as many of the shelters as identical as possible. Power, communications, and cabling solutions were standardized across the maximum number of shelters. Weight planning was

refined to ensure shelters were under their maximum weight. As part of meeting the security and usability requirements, color-coded cables and unique connector types matched to type of service were used. Furniture and electronics were also standardized. All non-server shelters were capable of all available types of service, allowing a change of usage for future operations.

LESSONS LEARNED

This section describes some of the insights gained and examples of problems encountered in the production of the CDHQ.

Overarching Lessons Learned

- To make quick, quality decisions, three-way partnerships (user, contractor, and government) at all decision levels were required to speed up the decision process and take advantage of team knowledge and experience.
- A consistent understanding of the constraints of the program was important. A constraint that we missed initially is that software constrains hardware. Users require software to perform their job. Once you know what software you have to use, you can determine what hardware you are "allowed" to use.
- Make sure you have enough people on the team from the beginning. Adding people late in a project is difficult, and the ramp-up time becomes expensive and counter-productive. This project was as successful as it was largely because of "heroes" on the team. Working excessive hours every day to meet a nearly impossible schedule can lead to costly mistakes, affect safety, and harm team morale.
- Do not increase the security posture of the work site too early. Increasing the security posture, from Unclassified to Secret, and Secret to SCI/Top Secret, too early caused unnecessary hindrance to productivity. Strive to work in an unclassified area as long as possible. Also make sure that there are sufficient cleared people available to do the work and escort others after the posture is upgraded.
- Government procurement programs may be required. Identify them early in the process. Requirement waivers are time consuming and costly.
- Keep in mind that procuring or fabricating items before understanding the requirements may make the project more expensive. You may need to purchase long lead-time items before you are certain you need them or understand the related costs. This can lead to wasted time and funds (e.g., returning unusable equipment). Be aware of items that have long-lead ordering time; if possible, confirm these items.
- Find out early if there are personnel and site requirements that must be followed. In this project, the Raytheon facility was a union shop, and therefore had to be involved in all property movement, which slowed down work and frustrated the development team. Later in the project, we had insufficient cleared personnel for union escort duty.
- Get the processes for configuration management in place as early as possible or this will become a problem at signoff. This should include documentation, license management, and property control.
- Some enabling resources may not be project deliverables, e.g., a local file server for file sharing, printers, and large format plotters. Get needed resources as soon as possible to leverage their potential as long as possible. Check existing resources to see if these items are available.

- Processes that are not critical early on but that will be critical later should be identified early and monitored often to avoid surprises and setbacks.
- Outsource rather than build in-house if it makes sense. We built CAT-5 cables in house, and then had to order commercial off-the-shelf cables because the self-built cables had quality control problems. In this case, building the cables in-house wasted labor, time, and money.
- Recognize tasks where parallel efforts can apply. However, keep in mind that certain processes or sets of processes are inherently sequential. If one engineer could implement a product in 10 months, giving the process to 10 engineers does not necessarily mean that the job will be done in 1 month.
- Testing and evaluation should be designed in from the beginning and should start at the beginning of the build process. If "new technology" is being used, make sure to test it in the target environment before committing to the technology. Legacy systems do not always work as intended when on newer platforms or operating systems.
- Designing early for the test and evaluation phase helps in the long run for customer acceptance. Providing the customer with a strong set of test documentation will help with the acceptance signoff; this can also affect safety and security.
- Integrated Logistics Support (ILS) cannot be ignored or drastically reduced. Issues of safety, spares, documentation, and training should be built in and kept updated throughout development. Safety issues must be followed and fixed immediately. A "zero spares" policy can slow the process by causing delays when equipment fails.

Interaction with the Customer

- Always consider customer needs. For example, the customer had just removed cameras from their JWICS J2 network at CENTCOM. We "forced" a camera on them at the user level because of a higher command level requirement for desktop collaboration. This required a significant effort to produce a client base load that could use the camera even though the camera would not work with their applications. We expected their applications would run in a VMWare session. This confused the users, and the applications ran considerably slower. We ended up removing the cameras and reverting to their approved baseline, running on NT not a VMWare NT session.
- Do not change applications unnecessarily. For example, the customer was using Norton Ghost™ for creating images of their machines. We chose PowerQuest DeployCenter™ instead. Although this worked, there was not an overriding reason to use one over the other. Using DeployCenter caused the user to have to learn a new product, and some incompatibility issues were discovered along the way.

Testing and Verification

- Make sure components are tested for actual requirements. For example, network cables built by the team were tested for 100-MHz operation but were required to run at 1-GHz operation. This interacted with the new communications and applications components, and software reduced confidence at integration and troubleshooting time, causing the team to rewire multiple times. This costs time and money.
- Create test plans (and training materials) before and during implementation. Identify interdependencies (software and hardware) so regression testing can be minimized.

- Some testing (experimentation) may need to be done early. If you are going to be using "new technology," make sure to test it in the target environment before committing to it.

CONCLUSION

This paper has explored some of the issues and insights to large team design and implementation of a complex product under unrealistic time constraints while maintaining levels of best practice engineering. While we attempted to prioritize, balance, and properly software engineer CDHQ, there were many wrong turns made due to the constraints and complexity of the product and team. It is hoped this will provide insight to other scientists and engineers so that they may learn from our experience. While not the perfect engineering delivery, the dedication and patriotic nature of those involved allowed it to be carried to completion, where it continues to serve the warfighter today.

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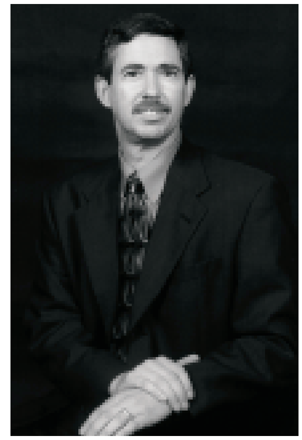

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Application of Disciple to Decision Making in Complex and Constrained Environments

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ABSTRACT
This paper describes Disciple, a decision aid based on artificial intelligence techniques, that subject-matter experts can train and use when making decisions under stressful, complex, and constrained conditions. The tool was developed and used under the Defense Advanced Research Projects Agency's High Performance Knowledge Base and Rapid Knowledge Formation programs at the George Mason University Learning Agents Laboratory. Disciple could contribute to enhanced decision-making efficiency as a decision aid in various domains, including military battle planning, as demonstrated by experiments described in this paper. The paper concludes with a discussion of future research in decision-support application tools.

THE KNOWLEDGE-ACQUISITION BOTTLENECK

For artificial intelligence to become useful in practical applications and environments, it is necessary to identify, document, and integrate into automated systems the knowledge that people use to solve problems. This process, called knowledge acquisition, has become a bottleneck in the development of artificial intelligence-based systems because knowledge acquisition is difficult, labor intensive, and error prone. This paper proposes a solution to the knowledge-acquisition bottleneck. It describes research in the development of a general methodology for modeling and representing an expert's problem-solving process in a knowledge-based agent through teaching-based ontology formation and rule learning. Based on the task-reduction paradigm of problem solving, this methodology is designed to accomplish the following functions:

- Helps the domain expert conceptualize the problem-solving process.
- Allows experts to document, order, and justify their decision-making process.
- Facilitates directly the expression of this information to the agent.
- Governs the entire agent-training and knowledge-base development process.
- Facilitates natural interactions for the agent to learn complex problem-solving rules.
- Supports reuse of ontologies and extension of ontologies for the problem domain.

EXPERT DECISION MAKING AND TASK REDUCTION

Experts constantly need to make complex decisions rapidly. Despite the complexity of the problem and the variety of approaches available, one methodology that is seen consistently in explaining and documenting the accessible parts of the decision-making processes is task reduction. Kirlik et al. have suggested that task-simplification strategies based mainly on perception and pattern recognition are fundamental to the novice-expert shift in dynamic decision making [1]. Task reduction is the process of taking a complex problem and reducing it to a series of less and less complex problems until relatively simple problems remain for which we have enough information to reach a conclusion [2, 3]. One key challenge was the collection and representation of this type of decision-making information. In a wide variety of domains, experts face cognitively demanding

tasks that have costly consequences for poor or ineffective performance [4]. Table 1 lists examples of challenging tasks and task-reduction techniques that experts use to approach and solve problems. Any automated decision-support tool needs to accommodate various task-reduction techniques of the application domain.

TABLE 1. Examples of decision-making under pressure and task reduction.

Attribute	Military Domain	Medical Domain	Manufacturing Domain
Knowledge Acquisition	Intelligence gathering	Diagnostic tests, examinations	Situation assessment
Source of Decision Pressure	Public perception, expectation of commanding officers, uncertainty of battle (the "fog of war")	Patient expectation, clinical schedule, progress of disease	Customer expectation, production schedule, marketplace competition, environmental dangers, government regulations
Consequence of Error	Failed military mission, loss of assets, wartime casualties, multiple fatalities	Untreated disease, treating the wrong disease, selecting wrong treatment cost, suffering, fatalities	Damage to products or materials, cancelled contracts, injury accidents, litigation, financial damage, fatalities
Examples	Developing a course of action (COA) or plan for a military operation	Diagnosing a disease when multiple diseases are present or when a group of symptoms has a combination of causes	Determining a strategy to transport heavy, expensive, unstable, hazardous and/or fragile materials or products in a factory/shipyard
Task-reduction Techniques	COA sequence according to published doctrine [5]	Step-by-step medical procedure	Safety checklists and engineering guidelines

DARPA HPKB AND DISCIPLE

The Defense Advanced Research Projects Agency (DARPA) High Performance Knowledge Base (HPKB) program ran from 1997 to 1999 [5]. The goal of HPKB was to produce the technology needed for the rapid construction of large knowledge bases (with many thousands of axioms) that provide comprehensive coverage of topics of interest, are reusable by multiple applications with diverse problem-solving strategies, and are maintainable in rapidly changing environments. HPKB participants were given the challenge of solving a selection of knowledge-based problems in a particular domain and then modifying their systems quickly to solve further problems in the same domain. (See, for example, [5] and [6]). The challenge problems tested the speed and efficiency with which large knowledge bases could be built.

The George Mason University (GMU) Learning Agents Laboratory's (LALAB) approach to HPKB was based on the Disciple Toolkit. Disciple's history, capabilities, inner workings, future research directions, and publications are described in detail in [7] and [3]. More information can be found on the GMU LALAB web page, http://lalab.gmu.edu. Disciple is a theory, methodology, and agent shell for rapid development of knowledge bases and knowledge-based agents by domain experts with limited assistance from knowledge engineers. The Disciple agent shell consists of an integrated set of knowledge acquisition, learning, and problem-solving modules for a generic knowledge base structured into two main components: an object ontology that defines the concepts from a specific application domain and a set of problem-solving rules expressed with these concepts. The process of developing a specific Disciple agent, starting from the Disciple shell, relies on importing ontological knowledge

from existing knowledge repositories, and on teaching the agent how to perform various tasks. This paradigm allows an expert to teach the agent as though it were a human apprentice by giving the agent specific examples of tasks and solutions, by providing explanations of these solutions, and by supervising the agent as it performs new tasks. In HPKB applications, a military expert taught Disciple to perform various tasks in a way that resembles how the expert would teach a novice. Disciple learns from the expert, building and improving its knowledge base and expanding its problem-solving capability. To conduct productive, interactive training episodes with Disciple, the experts must understand and document their decision-making process with respect to the examples to be used in the training episode.

HPKB COA CRITIQUING

The problem domain for one of the HPKB challenge problems was the critiquing of military courses of action (COA). A military COA is a preliminary outline of a plan for how a military unit might attempt to accomplish a mission. The example COAs used for this research and provided by the U.S. Army were specified in standard military formats consisting of a multi-paragraph textual description of the COA and a graphical representation of the COA in the form of a sketch using standardized symbols for units, activities, and geo-spatial relationships. The developed Disciple critiquer identifies strengths and weaknesses of a COA with respect to the principles of war and the tenets of army operations [8]. (See, for example, [5]). According to U.S. Army doctrine, the nine principles of war are objective, offensive, mass, economy of force, maneuver, unity of command, security, surprise, and simplicity. The Disciple-COA critiquing agent was developed to act as an assistant to a military commander and staff, helping them to choose the best COA for a particular mission. Application of the principles of war and the tenets of army operations as described in [8] is just the beginning of a good critique of a COA or plan. GMU's goal was to create a Disciple agent that contained the common understanding of the principles and tenets while retaining sufficient flexibility to allow rapid personalization by the experts training and using the agent.

AGENT DEVELOPMENT METHODOLOGY

The importance and usefulness of this methodology for modeling and representing an expert decision-making process, (as expressed in the thorough and accurate task-reduction steps, questions, and answers that the expert provides), is captured in our high-level research goals. Our objective is to have a domain expert interact directly and independently with the agent-building shell to train an agent to solve complex problems. Experts type natural language text, use mouse clicks to provide hints for explanation generation, and use mouse clicks to identify and select correct explanations. We do not expect an expert to create formal sentences for explanations or explicitly create rules in machine-executable language. This modeling provides the basis for the expert-agent interaction. For a detailed explanation of the following domain-modeling and representation-methodology steps, see [3].

1. Identify the high-level problem to be solved.
2. Identify categories of potential solutions.

3. Identify a specific example problem to be solved.
4. Brainstorm potential solutions for the example problem within a category of solution.
5. Select a potential solution to be modeled.
6. Identify the complete set of task-reduction steps for that potential solution.
7. Identify a question and answer that justifies progression from one step to another in the task-reduction solution path.
8. Identify concepts and features for Disciple's ontology.
9. Use the questions and answers as the basis for hints provided to Disciple (i.e., selecting relevant concepts, instances, and relationships).
10. Use the questions and answers to identify correct justifications among the justifications provided by Disciple during rule development or refinement.
11. Repeat the process for other solution paths.
12. Check solutions and refine rules for other data sets.

EXPERIMENTAL TRIALS AND RESULTS

The HPKB evaluation results are documented in [9] and [3]. In summary, these results show that Disciple-based agents built by teams of subject-matter experts (SMEs) and knowledge engineers using early versions of the methodology were highly effective in solving complex problems and produced very high knowledge-acquisition rates. A knowledge-acquisition experiment at the U.S. Army Battle Command Battle Laboratory at Fort Leavenworth, KS, determined the extent to which SMEs with no knowledge-engineering experience could train Disciple to critique a COA. SMEs modified and used models prepared by other military experts for our HPKB evaluations, and tested whether these models were appropriate and sufficient to support SME attempts to develop and train Disciple-based agents. The SMEs were U.S. Army combat arms officers with 16 to 22 years of military service. The experts received briefings that explained artificial intelligence, research goals, experimental design, Disciple, and the task-reduction models for problem solving. (See, for example, [10] and [11]).

During the experiment, the military SMEs each separately taught Disciple to critique a COA with respect to the principles of offensive and security. Starting with a conceptual modeling of the critiquing process for these two principles, they each independently developed a knowledge base in a single day. For one expert, training for the principle of offensive consisted of 101 minutes of expert-Disciple interactions. Disciple learned 14 tasks and 14 rules. Training for security consisted of 72 minutes of expert-Disciple interactions. Disciple learned 14 tasks and 12 rules. The knowledge engineer provided very limited training assistance. The knowledge-acquisition rates obtained during the experiment were very high (~9 tasks and 8 rules/hour expert). This knowledge-acquistion experiment is one of the most significant accomplishments of our research. To our knowledge, it is the first time a SME with no prior knowledge engineering experience has succeeded in extending a significant knowledge base in a very short period of time, without significant support from a knowledge engineer.

CONCLUSION

Our experimental results show that we have developed a general-purpose methodology and tool for expert knowledge acquisition based on apprenticeship multi-strategy learning in a mixed-initiative framework. This methodology enhances the ability of a domain expert with very little knowledge engineering experience to build a knowledge base efficiently. The Disciple methodology accomplishes six major functions: (1) helps the domain expert conceptualize the problem-solving process; (2) allows an expert to document, order, and justify their decision-making process; (3) facilitates directly the expression of this information to the agent; (4) governs the entire agent training and knowledge base development process; (5) facilitates natural interactions that allow the agent to learn complex problem-solving rules, and extend and correct the domain knowledge base; and (6) supports the reuse of existing ontologies and the extension of these ontologies for the problem domain.

DIRECTIONS FOR FUTURE RESEARCH

Modeling and ontology-acquisition activities can be automated, particularly with regard to the direct capture of ontology elements consisting of concepts, objects, and features. Disciple can be modified to learn more complex rules with improved methods. Disciple is being extended in an attempt to create intelligent agents to help identify candidate strategic centers of gravity for historic and modern crisis and wartime scenarios.

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Collaboration at SSC San Diego: A Decade (1993–2003) of Research

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ABSTRACT

SSC San Diego conducted one of its first collaborative technology demonstrations during Secure Tactical Data Networks-1994 (STDN-4), demonstrating the transport of video images from shore to ship at 3–12 frames per **minute.** ***Collaborative systems research has grown steadily throughout the Center during the ensuing years. Currently, several complex collaborative technologies are being demonstrated, including ship-to-ship collaboration in the current Joint Warrior Interoperability Demonstration 2003. With the proliferation of commercial collaboration technologies, the growing impact of joint operations on Navy missions, and the need to constantly refresh and integrate these technologies, there is a need to understand the history of research, development, test, and evaluation endeavors in this area. Prepared under the auspices of the Center for Command Technology Transformation, a cross-departmental team that monitors and supports collaborative technologies, this paper describes a decade of these activities conducted at SSC San Diego (1993–2003).***

INTRODUCTION

This paper provides a broad overview of collaborative systems and the human collaborative process by reviewing the various research, development, test, and evaluation activities conducted at SSC San Diego. These activities were undertaken for a variety of reasons, not the least of which is the continuing evolution to a fully netted force in which distributed operational personnel have the ability to execute their collaborative mission supported by the right information at the right time. In the mid-1980s, it became apparent that the transformation from large-scale VAX systems to integrated personal computers (via the ground-breaking work of Dr. Doug Englebart, Bootstrap Institute) would drive the way our forces would define the operational situation, analyze its potential, develop courses of action relevant to various scenarios, and craft multi-disciplinary *joint* execution. The ensuing goal was the electronic "netting" of the disparate elements of a mission, so that a seamless integration of computing resources, situation assessments (consistent operational pictures), perceived value of actions, and the actions themselves would combine synergistically. To achieve this seamless integration, two things must happen at the warfighter level. Distributed warfighters must be able to develop a consistent situation assessment (in other words, agree on the relative *meaning* of the tactical picture), and they must develop a coordinated, or more precisely, collaborative, process in which their *actions* can be synchronized to achieve mission objectives. This paper assumes that the development of distributed, collaborative processes is instrumental to the development of a shared understanding of the situation and that the execution of coordinated activities is essential to the successful achievement of the joint mission. These collaborative processes have many definitions, but the one we prefer was coined by a warfighter himself and captures the essence of that process:

"*Collaboration* entails the activities of two or more people working on a common goal/objective/object, with shared data, in which a product is left behind at the end of the process. In this context, the object may be a decision, a document, an image, a shared understanding of the situation (not necessarily, an agreement), or a plan of action."[1] [1].

Add to this definition the prospect of distributing team members (virtual teams), and you require an engineering component (networked systems) to the human process. In other words, the team relies on the network for

[1] This definition was coined by Jens Jensen, USPACOM J3 Deputy Director of the Operations Planning Team.

distributed communications and computing in support of team interaction. Unlike conventional co-located teams, a virtual team works across *space*, *time*, and *organizational boundaries* with links strengthened by "webs" of networked communications technologies. In essence, for virtual teams, *the network IS the computer*.™ [2] This implies that the study of collaborative processes and systems is not only a study in distributed human behavior, but also the study of the network architecture that underlies the communications and computing resources used by the distributed warfighters.

COLLABORATION "TECHNOLOGIES" OVERVIEW

Given the definition above, the goal of development activities in computerized support for collaborative team processes is in its ability to support three levels of warfighter activity: individualized and uncoordinated effort; multiple individual, coordinated, yet independent efforts;[3] and finally, the truly concerted or collaborative activities. A musical analogy to these three levels might be a soloist, a duet by concert members engaged in a scripted opera, and a jazz ensemble engaged in a continuing renegotiation of the musical product in real time.

Capabilities (and attendant technologies) that have evolved to support collaborative processes involve nine general categories. Several have appeared elsewhere [2, 3], but the list below has emerged through our own research into the field.

Information Sharing: This category includes tools that provide a common information space, sometimes with tailored workgroup applications, such as Lotus Notes® or non-interactive web pages.

Electronic Conferencing: Audio-video (real-time) conferencing and discussion databases (chat rooms) dominate this category, although the lines are blurring with the advent of instant messaging, as well as speech to text and text translation technologies.

Data Conferencing: The least understood, but perhaps one of the oldest technologies, shared whiteboarding, may become one of the most powerful tools to be developed. The ability of an application to provide a working surface that several users can control at the same time is unprecedented in the development of collaborative experiences. Similarly, the dynamics of application sharing and interacting with data in real time has only just begun to be investigated. The initial attempt to provide a WYSIWIS (what you see is what I see) surface has been the predominant theme in situation assessment technologies.

Group Authoring: Shared text documents for group authoring and editing have been the domain of intelligence analysis, doctrine and policy development, and document-dominant activities, such as those using collaborative Excel® spreadsheets. This has been the predominant application in business and staff planning environments.

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[2] Borrowing the tag line from Sun Microsystems, this concept is made apparent when one thinks of the isolated application test: installling an application and testing usability on a single workstation. With collaborative applications, you must be "networked" or you have little collaboration. This applies equally to telephones, fax machines, and the carrier pigeon.

[3] We have taken the liberty of defining coordination as the exchange of information that does not entail an elaborated exchange, which generally is the intuitive hallmark of collaboration. For example, target location data reported from a forward element to a rear echelon would be a coordination act. It becomes collaborative if there is an extended exchange during which clarification and possible disagreement and search for common understanding ensue.

Group Calendaring and Scheduling: Sharing, viewing, and editing team-members' schedules/calendars has been a mainstay of office systems for some time. Typically, two issues arise: at a personal level, people "lie" about their schedules in order to protect their time and, at a broader level, the ability to transfer dynamic changes to schedule information across a variety of peripherals (e.g., personal digital assistants) has not been a smooth path. Exercise planners were among the first to exploit this capability, with a rapid rise in maintaining battle rhythm management to follow.

Workflow: Automating routine tasks with user notifications and alerts is a growing area (having evolved from the manufacturing sector) and may be well suited to support some tactical processes [4].[4] Research and development is increasing in this area, given the current interest in "bots" and artificial intelligence software agents [5].

Group Decision Systems: Focusing on group process support (e.g., brainstorming, organizing groups, consolidating information or supporting a group decision) has been the domain of group decision support systems. The area saw an exponential increase in research and development in the late 1980s through mid 1990s, but has lain dormant for the past 3 to 5 years [6, 7].

Virtual Environments: The focus of development efforts in the collaborative systems arena has been on collections of group support functions in one application. There were only four predominant systems in 1997[5] but the area in general has now evolved into many separate multi-function applications specific to divergent work areas (e.g., finance, insurance, medical, etc.). However, five virtual environments dominate the commercial market, as well as the military area.

Simulated Environments: These are virtual environments with a heavy emphasis on three-dimensional (3-D) imaging and have a strong emphasis on the reality of the 3-D views. The modeling and simulation community predominates this area in their quest for the perfect immersive training system.

RESEARCH IN COLLABORATIVE PROCESSES

A short synopsis of a variety of research activities conducted at SSC San Diego in varying areas of distributed collaborative processes include the following projects (funding sources are given in parentheses):

1993–1995: Distributed Situation Assessment among Distributed Team Experts (Office of Naval Research [ONR]). This was a study of the use of electronic whiteboards and its application to collaborative situation assessment activities, given uniquely held information by individuals in a team of functional experts [8] distributed across an amphibious readiness group within a battle group.

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[4] The research headed by Dr. Glenn Osga on the Land Attack Combat System Human–Computer Interface project is a case in point.

[5] By 1997, the most comprehansive collaborative virtual environments associated with the military were LambdaMOO by the Xerox Palo Alto Research Center (PARC); Collaborative Virtual Workspace™ by MITRE; wOrlds (later called OrbitGold) by the University of Illinois, Urbana-Champaign (later transferred to the University of Queensland); Odyssey Collaboration System, built at SSC San Diego; and E-Room (a now defunct commercial vendor). All owe their evolution to the original text-based multi-user domains/MUD-Object Oriented (MUDS/MOOS) used on college campuses during the early 1980s before some of them evolved into very popular online, multi-user Internet games.

1996–1998: Distributed Command and Control Collaboration Joint Task Force Advanced Technology Demonstration (Defense Advanced Projects Agency [DARPA]). This demonstration project identified current collaborative technologies, leveraged the philosophy and insight of Dr. Douglas Englebart, and analyzed the ability of collaborative systems to support distributed command and control planning processes. This was one of the first integrated system development efforts to support distributed collaborative planning.

1999–2001: Decision Support System for Coalition Operations (ONR). This was a research analysis, as well as a development effort, focused on supporting coalition planners having to deal with cultural differences during distributed team activities while engaged in operations other than war (e.g., humanitarian assistance and disaster relief.)

2001–2003: Commercial Off-the-Shelf (COTS) Collaboration Tools for C^4: Then and Likely Future. This is an ongoing effort culminating in the tracking of over 600 collaboration and knowledge management web sites.[6]

2001–2003: Decision Making Constructs in a Distributed Environment (ONR). A study of the impact of (un)shared information on the quality of command and control decision making and how uniquely held information can be shared and integrated into the collective knowledge of a distributed command and control decision-making team.

1996–2000: Command and Control Multi-User Virtual Environments (ONR). The research and development of a multi-user virtual environment applicable to U.S. Pacific Command J3 (USPACOM J3) Operations Planning Team distributed activities, progressing from "flat" web services to 3-D client-server architectures, culminating in a federated server architecture, providing user-constructed virtual command centers, staff offices, and collaborative web services.

1999–2001: Distributed Interactive Environments: Heterogeneous systems Research and Development (ONR). This research focused on the evolution of multi-user virtual environments to encompass massively multiple-player Internet gaming network architectures, as well as a gaming infrastructure in support of online distributed rehearsals for the USPACOM J3 Operations Planning Team. The game was based on Dr. Richard Duke's gaming language and past experience building an organizational game for the Joint Chiefs of Staff. [9]

2002–2003: Virtual and Physical Command Centers (ONR). The proliferation of mobile and temporary command centers, alongside the rise of virtual (non-geolocated) command centers, has led to our research into their implications for battle rhythm management among distributed joint forces. Furthermore, we are analyzing the applicability of peer-to-peer computing architectures [10] to this new command environment.

DEVELOPMENT IN COLLABORATIVE SYSTEMS

Alongside the varying research efforts have been several collaboration system development efforts. These are a sample of those undertaken from 1993 through 2003.

Theater Area Replanning Graphical Execution Toolkit (TARGET). TARGET was one of the first applications of a Unix-based video-audio-whiteboard "desktop" conferencing system for shipboard use.

[6] Dr. George Seymour, SSC San Diego Code 244210, has been tracking these sites independently.

TARGET was demonstrated during the Secure Tactical Data Networks-1994 demonstration.

Common Operational Modeling, Planning, and Simulation Strategy (COMPASS). COMPASS was middleware developed to bring distributed collaborative planning, as well as modeling and simulation services to a wide range of command, control, communications, computers and intelligence (C^4I) systems. The focus was on building a bridge to provide interoperability among diverse protocols.

Odyssey Collaboration System (OCS). This collaborative virtual environment was the first to be built completely in Java™, exploiting LambdaMOO architecture. It provided a variety of collaboration services and was built under the Command and Control Multi-User Virtual Environments project for use by the USPACOM J3 Operations Planning Team. It continues to be used at U.S. Central Command (USCENTCOM) and has been employed by the Centers for Disease Control.

Distributed Computing and Collaboration Framework. This development effort produced a software package of peer-to-peer architecture design requirements and the testing of a multi-transport layer (focused initially on the user datagram protocol [UDP] and reliable user datagram protocol [RUDP]), with the goal of maintaining bandwidth efficiency under complex network conditions.

Low Bandwidth Enhanced Chat (LBEC). This current development effort, as part of the Virtual and Physical Command Centers' project, is focusing on the unique network requirements of Navy battle groups, from "big decks" to smaller attendant ships. It exploits a peer-to-peer collaborative system and is in the process of developing "bots" to manage network robustness and chat functions enhancements [9].

DoD Collaboration Tool Suite (DCTS) Engineering. This current development effort is in support of the Defense Information Systems Agency's (DISA's) Collaboration Management Office, as it distributes DCTS to all major joint command elements. SSC San Diego is responsible for the continued improvement, integration, and architectural development of the suite of tools that comprise the DCTS.

TEST AND EVALUATION EFFORTS IN COLLABORATIVE SYSTEMS

SSC San Diego has provided engineering data relevant to test and evaluation of C^4I systems since its inception. During the past decade, this has also included evaluation of collaborative systems. Beginning in 1993, when the Base Closure and Realignment Commission (BRAC) offices in the Pentagon and Camp Pendleton requested an analysis of Lotus Notes (along with its server replication software), to the present, with engineering tests of the latest peer-to-peer systems (such as Groove®), SSC San Diego has been able to provide realistic evaluations of varying collaborative technologies; the depth and breadth of its engineering laboratories allow emulation of normal to extreme warfighting conditions, from submarine, to ship, to air systems. SSC San Diego has supported the Collaboration at Sea project (with an emphasis on shipboard employment of Lotus Domino™ for server replication and Lotus Sametime® for collaborative services) that has provided collaborative services across the battlegroup where none were available previously. The engineering criteria that ensure that collaborative systems will work shipboard are encompassed in the Preferred Product List (PPL) process, which measures compliancy to Information Technology for the 21st Century (IT-21) mandates.

Some of the systems tested under this program include Internet Relay Chat, Microsoft NetMeeting®, Infoworkspace™, Lotus Domino/ Sametime, OCS, and Groove.

Several independent efforts are evaluating current collaborative services to understand performance constraints under varying shipboard (as well as joint) conditions. The Virtual and Physical Command Centers project is stress-testing Groove, as has the Grassroots Partnership, a cross-SSC San Diego team focused on providing support for testing of Groove™. (Their initial test has been with Groove on the Enhanced Position Location Reporting System.) Two major projects, Commander-in-Chief 21st Century (CINC21) and Joint Task Force Wide-Area Relay Network (JTFWARNET) have been testing the DCTS under network conditions experienced by land- and mobile-based command centers. CINC21 has focused on human–systems evaluation, while JTFWARNET has focused on systems performance under extreme conditions. The immediate future will entail an in-house planned test of the latest collaborative features provided by Microsoft under its Real-Time Conferencing Services system.

Finally, the Center for Command Technology Transformation, an internal cross-departmental SSC San Diego team, is consolidating Center test facilities virtually to provide a comprehensive collaborative system test battery (including human–systems evaluation and system performance testing) to determine the optimum configuration for various collaborative systems when employed under extreme conditions (those experienced by naval assets). The Center for Command Technology Transformation focus is on providing the joint warfighter with engineering data that will allow optimum use/configuration of "any" collaborative tool necessary to do the job.

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Task-Managed Watchstanding: A Software Architectural Framework

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ABSTRACT

In fiscal year 2002, the Office of Naval Research began sponsoring task-centric human–computer interface (HCI) design work in the land attack (LA) domain. The LA software development strategy is to aggressively exploit advances in applied computer science. The goal is to move from a very large-scale integration programming model to a distributed, shared component model. Doing this facilitates a shift in thinking about the nature of the HCI. In the new model, the HCI is no longer based on the commercial domain's application-centric desktop metaphor. Transaction-enabled task management components run in a business logic tier that is decoupled from the HCI. LA business logic continues to execute as before, but without writing to privately owned graphical user interfaces. The LA functionality and data sources are exposed to the task management HCI through Web services.

BACKGROUND

Osga [1] describes a revolutionary task-managed watchstanding system based on human factors and cognitive science principles. The Multimodal Watch Station (MMWS) is a response to the U.S. Navy requirement that shipboard command center crews "…complete time-critical and externally paced task assignments in an accurate and timely manner." The MMWS is made up of ergonomically designed hardware, a task-explicit human–computer interface (HCI), and advanced software infrastructure. The HCI is goal- and product-oriented, task-driven, and features interlinked display elements. It encourages users to engage in both naturalistic decision-making and critical thinking [2]. Follow-on HCI design work is focused on building high-quality, seamless task visualization tools in multiple operational domains. The potential benefits include less dependence on voice to transmit data, and enhanced individual and team performance. This recent effort is characterized as a Mission Centered Design work interface (MCD).

BUILDING A TASK MANAGED SYSTEM

In a task- and goal-explicit HCI such as the MCD, the usual office desktop, window, and document metaphors are replaced by graphical, on-screen task representations. MCD tools support decision-making and enhanced situational awareness. Features include at-a-glance decision aids, switchable task contexts, and seamless access to legacy systems.

Building a system with these attributes involves more than simply producing better graphical user interfaces (GUIs). The core logic is about task management, and each HCI component has a data model, a view, and a view controller. Some components are mini-applications, others are simpler display elements (thin components). Data are provided by a legacy system. Specifying and building such a system requires an HCI software engineering process. Fundamental process steps include:

- Performing task analyses to generate task requirements
- Developing HCI usability prototypes to generate HCI requirements
- Modeling task and workload management
- Selecting a suitable architecture
- Developing a system reference implementation

REQUIREMENTS

Operational domain factors that generate requirements include the following:

- Inter- and intra-watchstanding team collaboration generates requirements to support workgroup activities. Workgroup requirements influence architecture selection.
- Pre-existing stand-alone, stable legacy systems generate connection architecture requirements.
- Workload and attention management models spawn task and task management requirements [3], impacting business logic design.
- Decision support and supervisory control tools generate HCI requirements.

HCI LOGIC

MCD represents a radical departure from the familiar real estate and insurance office GUIs. Such commercial systems are application-centric, data-driven, and present the document metaphor in virtual windows. A decision tool-centric, task-driven HCI has an inherently different look and feel. For example, in air defense, an autolinking GUI function displays amplifying information in a decision tool whenever a map track is selected (Figure 1). Autolinking primitives are part of the MCD HCI core logic.

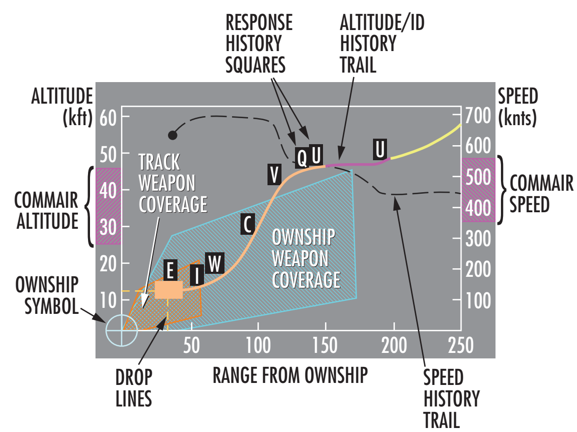

FIGURE 1. Track Profile at-a-glance decision support tool. Displays the currently hooked vehicle's track, including its altitude, speed, and response history. Implemented in Java™. Integrated through autolinking with other HCI components using Java technologies.

MODELING

A user-centric task analysis is performed on an operational domain to establish its essential use cases. Use cases capture dynamic aspects of a system and expose critical requirements. The identified cases are next catalogued into tasking families. A properly prepared use case can be mapped to an operational task model. Table 1 gives sample essential cases for three task families in the air defense domain.

Once the core task set has been identified, a task model is developed. A generic task is a goal-oriented work activity that results in a product [1]. As such, it contains both concrete and abstract elements. Concrete software activities such as read-ahead data caching are modeled in the task. Abstract elements such as the cognitive processes involved in making decisions cannot be modeled in software and are not included. They remain part of the overall task, however, and are explicitly supported in the HCI by the decision support tools.

TABLE 1. Essential air defense warfare use cases factored into three task families.

Monitor Air Situation	Conduct Intercept and Escort	Respond to Air Threat
Issue New Track Verbal Report	Manage DCA Cover	Issue Level 1 Query
Issue Update Track Verbal Report	Manage DCA Intercept	Issue Level 2 Warning
	Order DCA Action	Illuminate Track
	Manage DCA Engage	Order Cover

A task model is composed of a set of task super classes that declare common task attributes and behaviors. Domain-specific task functionality is added in derived concrete classes. This approach helps to decouple task logic from HCI logic, making the task classes reusable. A task model can write to multiple HCI components, providing display flexibility. A task model can also have its own GUI set, which means that tasks can be stored on servers, and can take their GUIs along when they move to clients. Figure 2 shows a task class component.

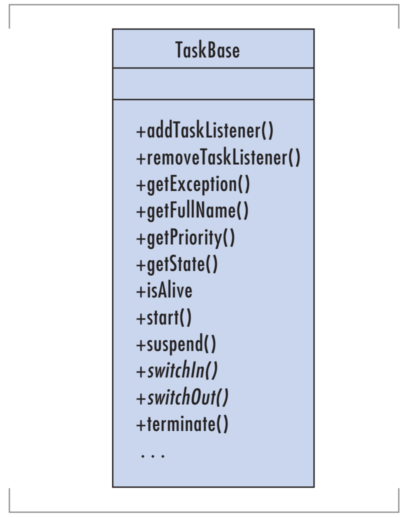

FIGURE 2. A task class component.

Tasks are triggered by environmental events and are assigned to workgroup members. The assignment logic is based on team workload and individual capability models [4]. These triggering and management functions are deployed in the architecture's application tier as task management business logic components.

Numerical computations, data management, and hardware control functions are performed by the legacy system. The task model gets structured information from the system "just-in-time" and presents it in the HCI in the form of results, recommendations, and draft products. The model directs the legacy system, through a connection mechanism, to execute functions and provide status, drill-down, and environmental information.

Figure 3 shows a task management, decision support conceptual model.

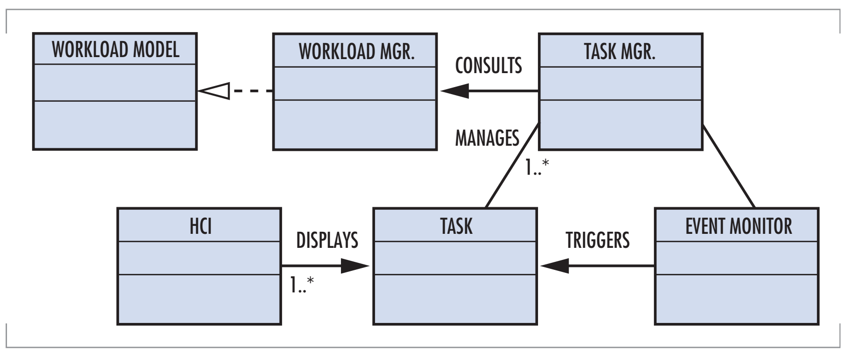

FIGURE 3. MCD task management conceptual model.

APPROACH

Web and emerging enterprise technologies map well to MCD features and functions. While many new technologies are still evolving, others are mature enough to exploit now. New technology use is often associated with the following "best" practices:

Design for the enterprise. The definition of "enterprise" scales from combat information center teams, to the entire ship, to the battlegroup, and beyond. Large, stable legacy systems, which should be left undisturbed, form the enterprise's information management backbone. Enterprise components such as the MCD Task Manager tap into the ship's information management backbone through standard connection mechanisms.

Adopt or adapt a standard software architecture. Industry groups are developing architecture standards. Multi-tiered architectures enable developers to separate data display from data processing and data storage. Benefits include code reuse, scalability, and ease of integration.

Focus on writing business logic while leveraging commercial and open source "enabling" technologies. Application servers provide multi-user access to shipboard planning and tactical components. The MCD management components are served across the enterprise. This means that personnel not stationed at consoles have access to the same information as the watchstanders.

Maximize the use of standard communication protocols. MCD's adapter tier accesses legacy information management components through native protocols, and publishes to clients over high-level, standard protocols such as Simple Object Access Protocol (SOAP). This strategy helps to reduce code life-cycle costs.

MCD ARCHITECTURE

A composite system's architectural form can be allowed to accrete over time as disparate legacy systems are interconnected. The final architecture is defined after all the connections are realized. This process produces the familiar, and yet always puzzling, lines and boxes architecture. An alternative is to specify the architecture as soon as the essential use cases have been defined, their requirements identified, and the conceptual models blocked out. Example candidate architectures include the blackboard model, hub and spoke, client/server, n-tiered, International Organization for Standardization (ISO) network layer model, and neural net.

MCD has workgroup requirements and legacy system connectivity requirements. Current best practices suggest adopting an n-tiered architectural approach [4]. The MCD task and workload management components represent "business logic" and belong in the application tier. HCI display components properly reside in the presentation tier. Legacy system adapters and Web services make up the connection sub-architecture. The corporate system is its own architecture, and makes up the legacy tier.

Figure 4 depicts MCD deployed as a distributed, task management enterprise application. Presentation components are both thin and thick, as dictated by HCI autolinking requirements. Thin components run on watchstations, on laptops, and may eventually run on personal digital assistants (PDAs). The Task and Workload Managers are transaction-capable, and are implemented as Enterprise Java Beans™ [5]. Task templates are stored in local databases and are instantiated on receipt of external events such as a call-for-fire. Instantiated tasks execute on clients, mediating the presentation of data, status, and draft products in the HCI. The connection tier "talks" native protocol on the legacy side and standard Web services on the task management side. The legacy system's public functions have been exposed through a variety of means, including native application program interfaces and Common Object Request Broker Architecture (CORBA®).

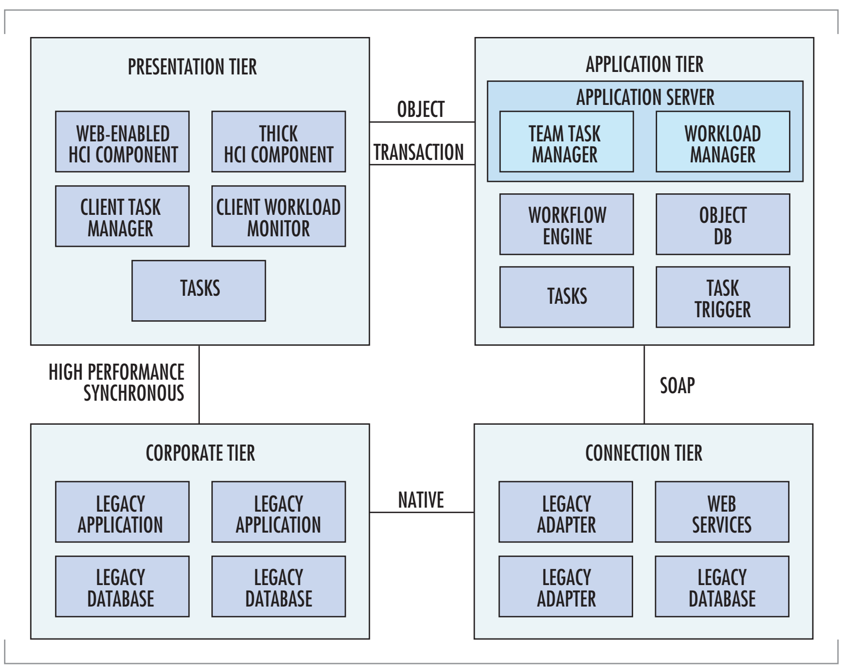

FIGURE 4. Conceptual model of an n-tiered task management system. The user-centered HCI contains decision support and supervisory control GUI elements. The Presentation and Application tiers connect to corporate information management systems via Web services and custom adapters.

CONCLUSIONS

Building a user-centered task visualization HCI is a novel undertaking. It is also a challenging proposition because traditional GUI development approaches and tools are not flexible and powerful enough. The answer is to exploit new enterprise technologies, combine them with object modeling methodologies, and drive the development effort with requirements derived from user task analyses. The resulting product will be a user-centered task management system that can be connected to a variety of legacy applications.

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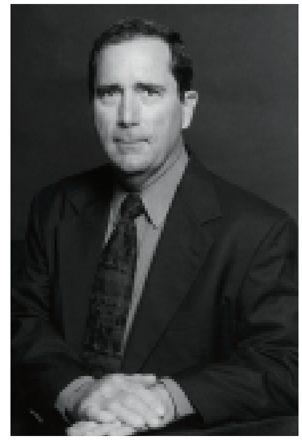

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Current Work: HCI and task management architecture design and development.

The REDS Dynamic Decision Support Suite

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ABSTRACT

The Real-time Execution Decision Support (REDS) program is developing software tools that support air strike mission planning and dynamic replanning for time-critical operations. These tools are hosted on an enterprise architecture that integrates distributed computing technologies to yield seamless transitions from planning to real-time mission execution and monitoring while supporting tailored information transfer among planning and operational elements. Thus, the warfighter realizes an increased ability to respond to changing battlefield and operational conditions. In this state-of-the-art concept, real-time mission repair, replanning, and retargeting of in-theater assets is achieved. The REDS Dynamic Decision Support Suite serves as a force-level support tool for real-time retargeting by providing infrastructure and algorithms for situation awareness, risk assessment, and near-optimal strike asset allocation.

INTRODUCTION

The Real-time Execution Decision Support (REDS) program is developing automated force-level decision aids, or software tools, that facilitate situational awareness, risk assessment, and responsive retargeting for naval air strike assets such as those shown in Figure 1. These decision tools, being developed as an integrated Decision Support Suite (DSS) referred to as the REDS-DSS effort, include three major tools. The Sensors, Intelligence, ROEs (rules of engagement), and Environment Network (SIREN) module supports situation awareness. The Risk Assessment and Validation Engine (RAVE) provides risk assessment capability. The Rapid Asset Pairing Tool (RAPT) provides responsive targeting options generation to the kill authority.

Under development as an Office of Naval Research (ONR) Knowledge Superiority and Assurance (KSA) Future Naval Capability (FNC), these tools are slated for transition to the Joint Mission Planning System (JMPS) force-level release.

The dynamic arena in which tactical air assets operate dictates the need for flexible targeting options generation in the event of significant changes in the environment, introduction of high-priority targets, or targets of opportunity. The ability to generate weapon-target pairings is complicated by the incorporation of advanced munitions.

An automated force-level planning tool must provide automated flight-planning and mission-planning capabilities to the tasking authority. Requirements for an automated flight-planning tool include automated routing, platform capabilities and performance data pulls, and weather forecasts. Aspects of an automated mission-planning tool include the ability to coordinate disparate aircraft, sensor, and weapon systems, deconflict routes, and evaluate mission effectiveness and platform risk. In concert with the commander's intent, this tool should also support automated retasking and asset allocation [1].

The REDS-DSS tools allow a tasking authority to respond to dynamically changing targeting situations using in-theater assets. The near-term decision support objective is to move an air-strike package en masse to nearby high-priority targets as well as react to changes in the environment. The long-term objective of this work is to provide a capability to retarget strike assets beyond the original strike area with the potential inclusion of joint and/or allied assets.

FIGURE 1. The REDS-DSS provides decision support for naval air strike.

SITUATION AWARENESS

The cornerstone of time-critical strike resides in rapidly assessing the common operational picture (COP) in light of mission objectives. The REDS-DSS accomplishes this by pulling forward track information and associated system capabilities, performance data, and mission plans. The SIREN module has been developed in an effort to meet this requirement. SIREN's objectives include:

- Monitoring the environment
- Assessing changes to the entities in the environment
- Identifying entities in the environment
- Retrieving entity capabilities and performance information
- Managing the prioritized target list
- Retrieving mission data

Interfaces to a multitude of systems enable the SIREN module to pull forward the capabilities and performance of entities in the COP. A Global Command and Control System-Maritime (GCCS-M) feed provides track information complete with Red Force electronic intelligence notation (ELNOT). The ELNOT number is passed to the EA-6B Tactical Information and Report Management System (ETIRMS) to obtain a system designator. The system designator is then passed to Quiver, a Red Force Threat and Target database, which returns the Basic Encyclopedia (BE) number, location, time stamp, and corresponding capabilities and performance parameters of the threat system. In the event of unknowns, a composite track correlator capability estimates the entity type based on the track dynamics and any associated intelligence information.

In addition to supporting Blue Force capability and performance data from the Joint Mission Planning System, SIREN provides an interface to the Element Level Planning (ELP) Tool/Strike Planning Folder to combine mission-planning information with corresponding Blue Force track data to form a comprehensive data object for risk assessment and dynamic asset allocation.

As new entities (or tracks) enter the specified region of interest, they appear on the Gantt timeline based on their time stamp (Time-in-COP, or TIC) and a textual window alerts the user that a new entity has entered the COP. When the entity is no longer represented by a track, it leaves the COP (Time-out-COP, or TOC), terminating the Gantt timeline. Trends can be readily visualized via the Gantt bars as entities become active and inactive within the COP based on their TIC-TOC indicators. Figure 2 shows a prototype of the SIREN Client Viewer.

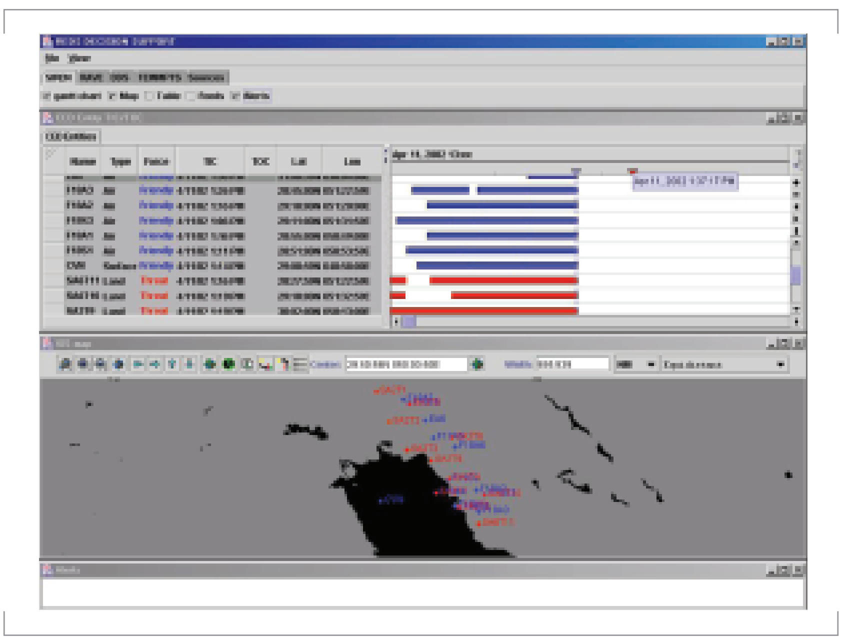

FIGURE 2. The REDS-DSS Client Viewer supports a Gantt presentation of when entities enter and leave the COP as well as a map interface and alert window. This is a view of the SIREN module interface. Tabs are provided to access other modules.

A map viewer is provided as part of the SIREN user interface. This viewer can accommodate user preferences. For example, the user can specify the entities to monitor by selecting them from a list of entities in the COP. An intelligence officer can display the enemy order of battle and keep the watchstander abreast of any changes that may affect the mission. The airboss can watch the execution of the airplan when entities under his purview execute their mission.

Additional viewer functionality includes the ability to toggle entity fades in the map as a function of the latency of the data and system type. Thus, the user can readily assess the latency of the track information. The user can also specify regions of interest such as no-fly zones or air corridors that can be used to generate alerts should an entity enter, or leave, a specified volume.

Finally, a prioritized target list management function is provided to support the insertion of high-priority and/or time-critical targets. Existing targets are taken from the Joint Integrated Prioritized Target List (JIPTL); the list is augmented as necessary with the insertion of targets of opportunity. This insertion of high-priority targets or targets that have short windows of opportunity has the potential to initiate the RAPT to generate new weapon-target pairing options.

RISK ASSESSMENT

The evolutionary threat arena requires the constant monitoring of threats to all Blue Force entities in the battlespace. This capability is paramount in triggering a dynamic retargeting event. RAVE is being developed to support the following functionality:

- Determining risk to entities in the COP
- Providing a risk-based trigger function to the dynamic retasking tool
- Validating threat capability based on situational information
- Providing a mechanism for displaying risk evaluations in real time
- Quantifying deconfliction as part of risk assessment

The methods implemented for ascertaining risk to a Blue Force entity depend on the entity state. A static entity can be evaluated based on its current position and proximity to red forces and Red Force capabilities. A mobile entity must be proactively evaluated based on its planned route or perceived path.

For Strike-Air Assets, the RAVE tool uses kill-chain analysis to quantify and assess platform risk based upon the threat laydown. Templates of the radar signature for tactical aircraft of interest have been generated against various threats. These templates are used for determining the level of exposure that an aircraft has against a particular threat system based on the aircraft's orientation, altitude, and slant range from the threat. The technique for estimating the threat-based risk component to an airborne asset is a function of exposure time and threat capabilities. The route is decomposed into 1-second intervals based on flight performance parameters and then evaluated to determine if the route points are within threat range. The continuous time that a platform is within threat range is then integrated and compared with a risk-level threshold. When the platform is no longer within tracking or acquisition range, the risk level can be zeroed out based on the required time of continuous non-exposure to the threat to break the radar lock. Risk from multiple threats on a single platform is assessed using the Hamacher sum as discussed by Sugianto [2].

For the current implementation, the $l\infty$ norm can be taken as the overall risk of the route.

An example illustrating this concept is shown in Figures 3 and 4. Figure 3 shows a hypothetical route and crossing through a stationary (threat-centric) template. For this example, the template does not change with respect to aircraft orientation, altitude, or range. Figure 4 shows the results of evaluating the route through the threat region based on kill-chain analysis. The top portion of Figure 4 indicates when the aircraft is within range of the threat's radar. The middle portion of Figure 4 shows the evaluation of the continuous time of exposure relative to the risk threshold (shown by the dashed line). The bottom part of Figure 4 shows the normalized risk along the route.

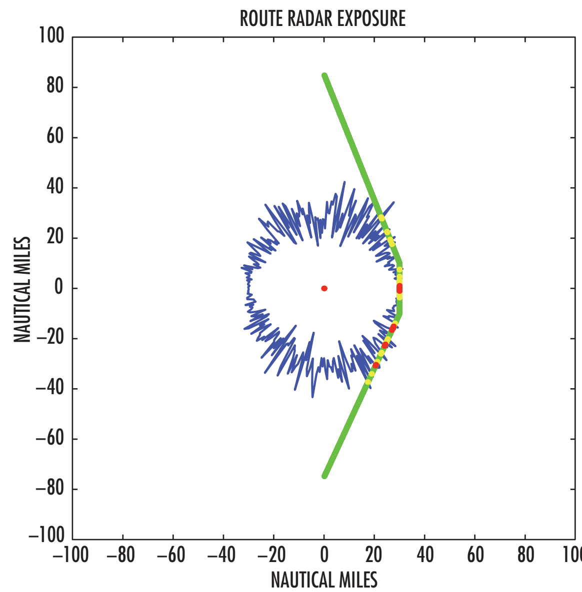

FIGURE 3. A hypothetical example of the exposure template used to assess the risk to positions and routes through enemy threat laydown.

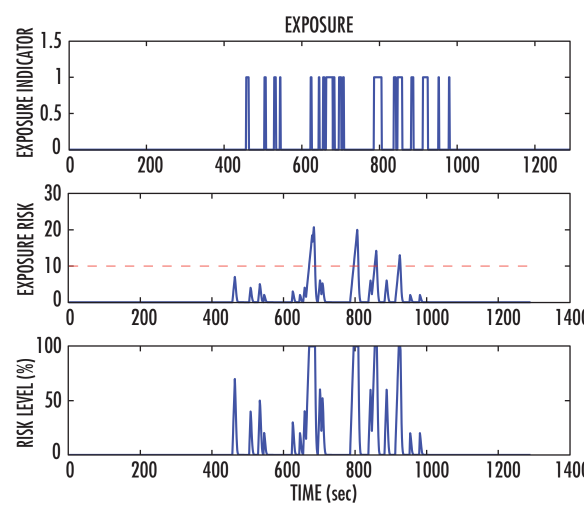

FIGURE 4. Quantification of the RAVE kill-chain analysis for assessing risk.

RESPONSIVE TARGETING

RAPT supports the dynamic reallocation of strike force assets. While the optimization algorithms are generic, the focus is on naval air strike missions [3]. The objectives for the RAPT module include:

- Rapid weapon-target pairing options generation to tasking authority
- Providing an automatic routing capability
- Dynamically reallocating assets based on high-priority target trigger
- Dynamically reallocating assets based on changing environment
- Minimizing risk and collateral damage while maximizing effectiveness

The overarching goal of the RAPT is to provide weapon-target pairing recommendations to a commander with tasking authority. The RAPT can be triggered based on the insertion of a high-priority target into the mission objectives as well as excessive risk levels of threats impinging on the Blue Force assets. An example of the latter is shown in Figure 5. As shown, a platform launches with an inherent risk level. If environment changes adversely, affecting the risk level of a platform, the RAPT is triggered to generate weapon-target pairing recommendations in a continuous manner to facilitate options generation at some time T. However, weapon-target pairings do not constitute a complete solution. Route information, and the risk assessment and deconfliction of that route, must also be provided with any recommended weapon-target pairings to form a complete solution. These options are presented to the tasking authority for their modification and/or approval.

The formulation of the objective function for the strike asset optimization problem is given by McDonnell et al [3]. The optimization engine has been chosen based on the need to support continuous options generation, a readily modifiable objective function, and the potential to generate

global solutions on a multimodal surface within a myriad of constraints. The optimizer chosen is based on evolutionary computation techniques augmented with case-based reasoning methods. Preliminary studies [4] have shown that the optimizer works rapidly for relatively small problem sets such as that shown in Figure 6. Allocation of 20 platforms with 80 assets attacking 20 targets can be performed in seconds with a relatively short number of iterations as shown in Figure 7.

While the convergence speed of these results is encouraging, additional work needs to be done to address allocating assets under scheduling constraints. Namely, the choreography of a naval strike mission revolves around time-on-target, Suppression of Enemy Air Defenses (SEAD) timings, and tanking constraints. To help decouple the problem, the search is partitioned such that attack assets are only allocated to attack targets, while SEAD assets are only allocated to SEAD targets.

A tradeoff exists between maximizing mission effectiveness and minimizing overall risk to the mission. A slider that emphasizes the effectiveness/risk tradeoff is provided to the tasking authority to incorporate the commander's intent into the optimization engine. Another objective that is being incorporated is "persisting" the airplan [5]. That is, changes to the existing missions should be minimized to prevent wholesale modifications of the planned missions.

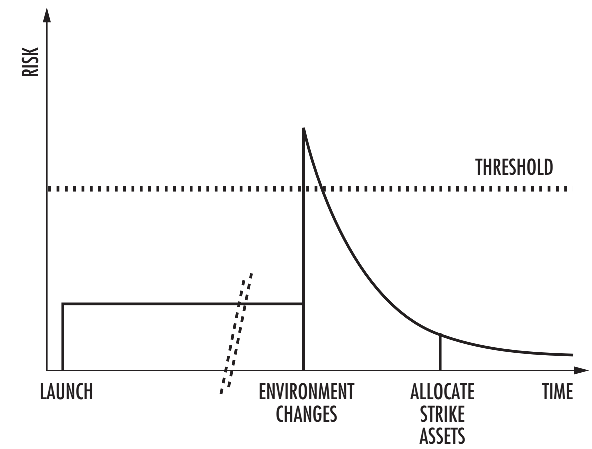

FIGURE 5. A notional depiction of increased risk providing a trigger to the RAPT engine based on environmental changes and subsequent optimization to reduce the exposure.

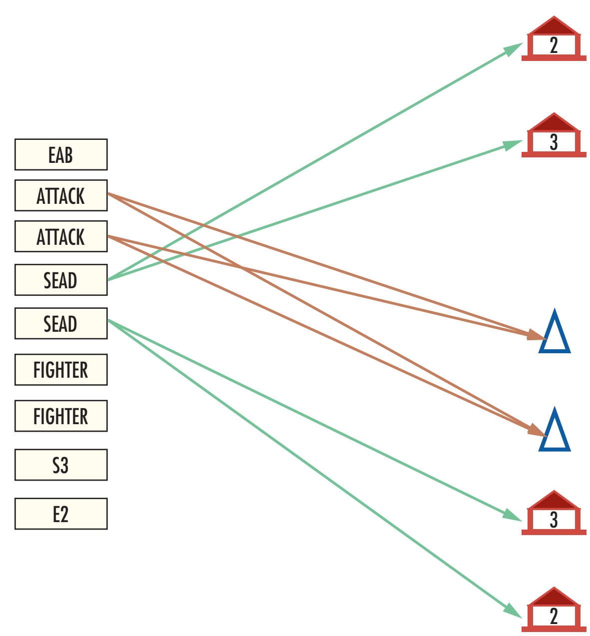

FIGURE 6. RAPT provides dynamic weapon-target pairing for many-on-many assets on objectives.

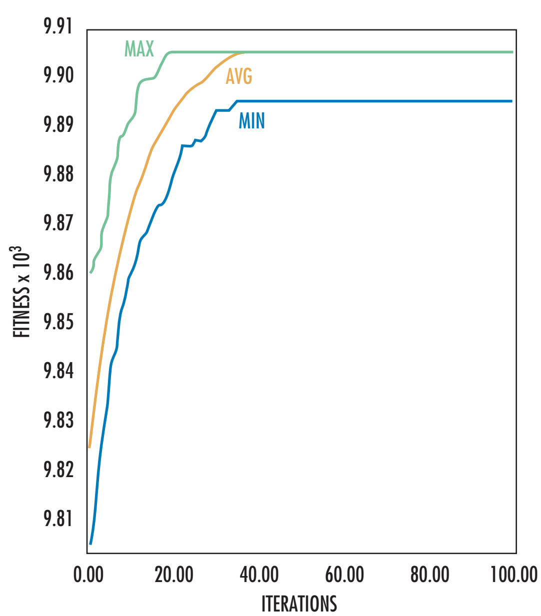

FIGURE 7. An evolutionary algorithm can generate near-optimal weapon-target pairings in a matter of seconds.

CONCLUSION

The REDS-DSS tools will provide the warfighter with an increased ability to respond to changing battlefield and operational conditions while maintaining operational tempo. With this suite of tools, mission repair, replanning, and retargeting of in-theater assets may be achieved in response to high-priority targets and intelligence updates.

The REDS-DSS tools are hosted on a J2EE enterprise architecture. This architecture is open and extensible and has interfaces to a multitude of legacy systems such as the Joint Munitions Effectiveness Manual (JMEM) and data sources such as GCCS-M. In addition, Enterprise Java Beans are being employed so that interfaces with other legacy applications such as the Portable Flight Planning System (PFPS) and new services can be readily provided as they become available [6].

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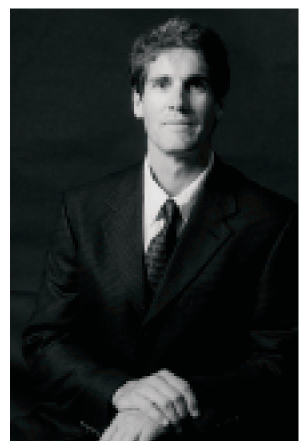

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Providing a Multilevel Secure Solution for the Rapidly Expanding World of C4I

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ABSTRACT

This paper describes the MLS solutions developed by the Ocean Surveillance Information System (OSIS) Evolutionary Development (OED) Project. OED's design is based on the tight coupling of a commercial trusted operating system as its foundation and a large amount of government and commercial single-level applications software, with a small amount of multilevel trusted application software. OED's multilevel approach implements a process where data's original security domains are preserved throughout the analysis and fusion process. Information is automatically released according to its original security domain, and fused intelligence is released according to the sum of its security domain.

INTRODUCTION

The U.S. military today and in the future will conduct operations within the joint, allied and coalition environments simultaneously. Within this context, the ability to exchange information across multiple security levels has become an even greater necessity. To effectively use today's precision weapons and ensure a common battlefield picture, our allied and coalition partners must be fully integrated in and interoperable with our command, control, communications, computers, and intelligence (C4I) environment. The U.S. must be able to operate in an environment where the data flow rapidly and seamlessly between the Top Secret sensitive compartmented information (SCI), general services (GENSER), and coalition participants. This architecture must provide the ability to acquire, store, and disseminate content to and from these diverse security domains. In addition, it must allow users with varying clearances to securely collaborate with one another using both structured and unstructured methods. The architecture must demonstrate that it can accommodate these features in an approach that is scalable (from a hardware perspective), supportable (from a manpower perspective), and able to be implemented (from an engineering, security, and acquisition perspective).

The Navy's Ocean Surveillance Information System (OSIS) Evolutionary Development (OED) is the only system that is fully accredited for multilevel secure (MLS) processing by the Department of Defense (DoD). It was first certified and accredited for operational use in September 1998 and has been operating at U.S. joint intelligence centers and foreign national intelligence centers since then.

OED evolved out of the OSIS program of the 1970s. Initially, OSIS was established to support decision-makers at all levels of command. OSIS emerged as a combination of personnel, facilities, computers, communications, and procedures designed to receive, process, correlate, and disseminate evaluated land, air, and ocean surveillance information. In 1997, the OSIS Baseline Upgrade system became known as OED, which now serves as the backbone automated information fusion system currently supporting a multilevel common operational picture at U.S. and foreign intelligence centers. There has also been significant interest in leveraging OED's MLS and intelligence capabilities by the operational fleet. Consequently, OED is currently undergoing test and evaluation for the afloat community.

OED operates at the Top Secret/SCI level; its design is based on a commercial trusted operating system (Hewlett-Packard Unix/Trusted Operating System [HP-UX/TOS] 10.26) and a combination of government and commercial single-level applications software.

This paper describes the high-level design, implementation, and deployment of OED.

MLS DESIGN

MLS is a complex concept and a highly specialized area of computer security. MLS means different things to different users:

- External MLS – the ability to take information/intelligence from multiple, trusted security levels and disseminate derived products out to multiple, trusted security levels.
- Internal MLS – the ability to restrict access to data on a network depending on the security level of the user.
- MLS communications – systems that can take message traffic from multiple communications paths and transmit messages out via multiple communications paths.
- MLS C^4I – a system that can take data from multiple security levels and preserve the data's security label as it moves through the analysis, fusion, and dissemination process with a high level of assurance. This assurance means that the data processing is in accordance with an approved security policy.

MLS is often confused with the concept of multiple security levels (MSL). MSL is a class of system composed of relatively untrustworthy single-level systems. Separation of data and trust is placed in controlled interfaces between the less trustworthy components. These controlled interfaces (e.g., guards and sanitizers) are typically smaller automated information systems running a dedicated program, providing a dedicated function.

MSL implementations maintain multiple instantiations of servers, clients, applications, and databases to serve each security enclave and pass the data up or down using guard and sanitization tools. Because of this, it is not uncommon to find three or more workstations in a single workspace aboard our ships.

OED is DoD's only accredited multilevel Protection Level 4 (PL4) secure intelligence processing and data dissemination system. It is certified and accredited by the Special Security Office Navy and the Defense Intelligence Agency. It serves as the backbone automated information/fusion system supporting a multilevel common operational picture at U.S. and allied joint intelligence centers. OED typically operates at the Top Secret/SCI level and automatically and manually disseminates formatted and narrative messages at multiple security levels. OED's most current Release 4.0.4.3 software and hardware has been certified for PL2 (formerly known as compartmented mode) for internal communications and PL4 (formerly known as multilevel mode or MLS) for external operations.

The system can automatically receive and generate tens of thousands of narrative and formatted messages per day, from a variety of different security domains and communications sources (these include Officer in Tactical Command Information Exchange Subsystem, Tactical Data

Information Exchange Subsystem, and Defense Message System). The system is also directly connected to the Automatic Digital Network (AUTODIN) Bypass systems (i.e., Communication System Processor and Newsdealer) for connectivity with allies, coalition partners, and worldwide SCI sensors and command centers. OED's MLS communications subsystems ensure rapid delivery of both record message traffic and intelligence broadcasts in support of the Unified Commanders-in-Chief, Joint Task Force commanders, and coalition warfare partners. OED's accredited MLS design allows simultaneous data outputs to a number of security levels. The typical "lowest common level" problem in coalition warfare is completely avoided. See Figure 1.

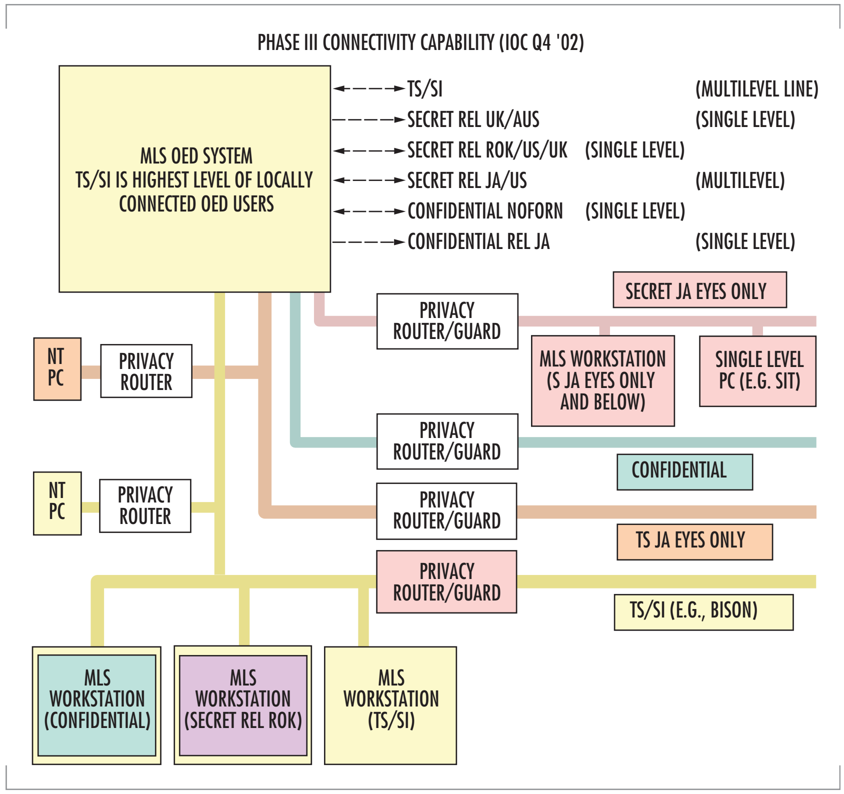

FIGURE 1. Phase III connectivity.

The information flow of the OED system involves input, internal processing, and output capabilities. Inputs into the system arrive from external sources in the form of messages via communications circuits and data directly entered by the user. These messages are received as either formatted messages, which can be automatically processed by the system producing formatted output messages, or as narrative messages (i.e., unformatted messages). Unformatted or narrative messages cannot be automatically processed for output; however, every incoming message is automatically and rigorously validated for overall integrity, and a security label is automatically attached to the data. Only formatted messages with valid security labels are allowed to contribute to the labeled track data picture. See Figure 2.

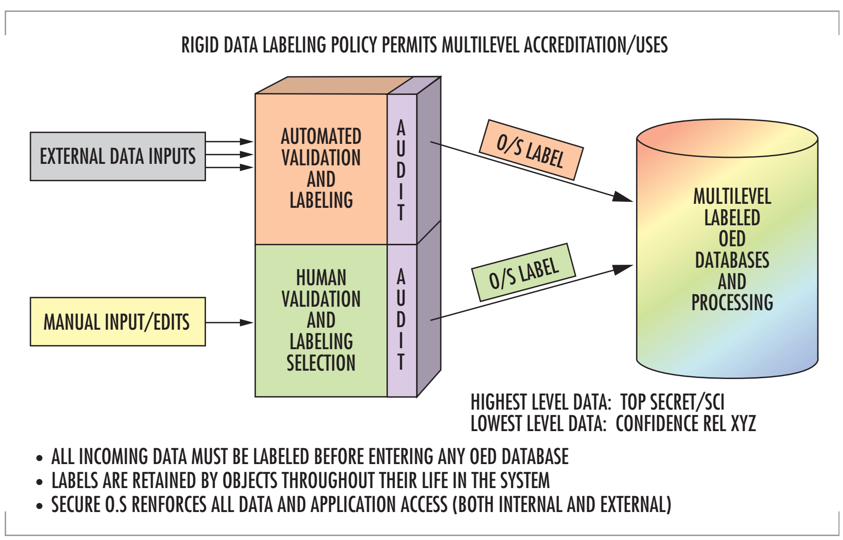

FIGURE 2. Rigid data labeling policy.

OED software does more than support formatted and narrative message processing. OED applications include:

- Robust message profiling/retrospective searches.
- Unique data-mining tools (with the Contiguous Connection Module).

- Automated correlation of incoming contacts to tracks in a single multilevel track database with significantly improved track history for analytical use.
- Multiple databases that contain information to assist the intelligence analyst in correlation and analysis.

All OED equipment resides in secure spaces. Due to physical security issues, all personnel granted access to the area must be cleared to the highest level of the data processed by the OED system. All workstations/servers are interconnected via a local-area network (LAN), which uses HP 10.26 Compartmented Mode Workstation (CMW) operating systems and multilevel, labeled, high-speed network communications between the systems.

All OED workstations (HP TAC-3, TAC-4, and TAC-4 follow-on computer systems) and servers use the trusted operating system with a common data encoding file that is used to generate and validate all security labels for files, messages, and processes in the system. Separate network interface cards are used to control data sent to and received from each network level. The OED central processing unit consists of one HP CMW server (9000/J5000 or J6000) connected via Ethernet LAN to several HP Model J5000 (or B2600) client workstations on the SCI High LAN. All systems support one or two 19-inch or 20-inch color monitors. All systems use the HP-UX/CMW 10.26 secure operating system.

MLS IMPLEMENTATION/DEPLOYMENT

OED Release 4.0.4.3 software has been installed and certified at a number of U.S. and allied intelligence sites. OED is a mission-critical system at the three operational U.S. joint intelligence centers (Joint Forces Intelligence Center, Joint Analysis Center Molesworth, and Joint Intelligence Center Pacific). OED is also the central intelligence analysis system at four foreign national-level intelligence centers (London, England; Sydney, Australia; Funakoshi, Japan; and multiple sites for the Republic of Korea Navy). In addition, OED is sited at six smaller U.S. government sites, and most recently aboard the Commander Second Fleet (C2F) Flagship, USS *Mount Whitney* (LCC 20), the program's first afloat installation. See Figure 3. OED was used operationally during NATO Exercise Strong Resolve 2002, Joint Fleet Exercise 02-02, as well as during daily intelligence watch and analytical operations in support of the C2F mission. OED responsibilities on the ship included support for U.S. SCI and NATO operators within the dual physical confines of the commander's joint intelligence center. OED capabilities used included the message-handling system, multilevel common operational picture, and data mining. In addition, OED provided a consolidated messaging architecture that allowed direct connectivity to all security domains for receipt, archive, and generation of message traffic. Connectivity to the Allied Information Flow System (AIFS) was achieved during initial accreditation. OED was assessed by C2F as operationally effective with significant potential to be the Navy's intelligence core system for a robust, collaborative, information and analysis environment afloat. A similar system is scheduled for deployment aboard USS *Blue Ridge* (LCC 19) in support of Commander Seventh Fleet.

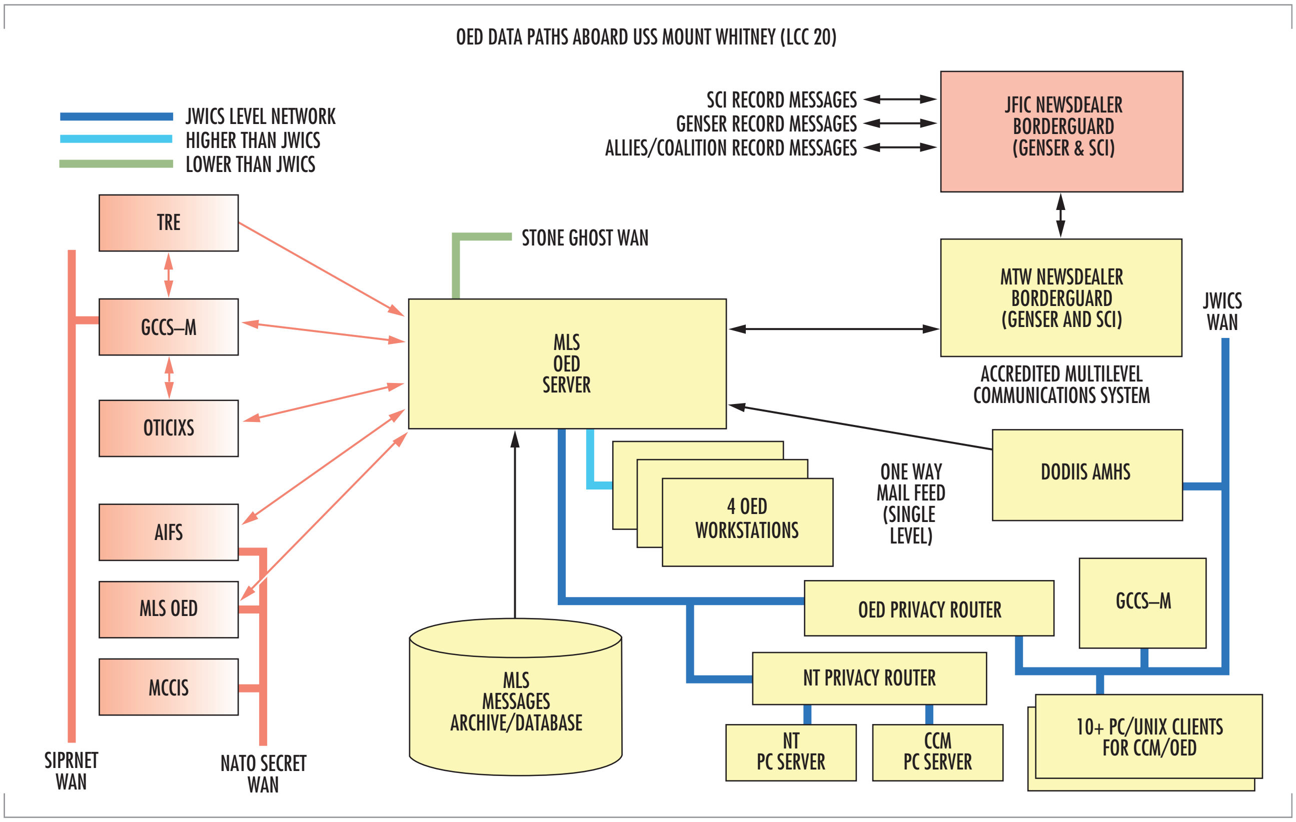

FIGURE 3. OED data paths.

CONCLUSION

The War on Terrorism has highlighted the need to effectively and efficiently move data across a wide variety of security domains. This requirement exists not only in the area of allied and coalition warfare but in the area of homeland security and defense as well. The events of September 11th showed the need to move relevant data across military and law enforcement domains as well.

To meet the diverse information needs of joint, allied, and coalition partners, the DoD has implemented MSL solutions both ashore and afloat. These implementations have resulted in multiple instantiations of servers, clients, applications, and databases to serve each of the diverse security enclaves. This architecture has created an environment that hampers interoperability, impedes data fusion, creates multiple (and divergent) common operational pictures, results in data loss, and creates unnecessary duplication of hardware (increased space, power and networks) and a concomitant increase in operations and maintenance costs.

The OED system has untapped potential to be the core intelligence system both ashore and afloat for the U.S. and its allied partners. OED's MLS features can serve as the core technology on which future C4I systems, networks, and databases operating at multiple classification levels can be effectively accredited and combined. As the system evolves, it will allow appropriately cleared analysts and watch officer's high-speed access to information across multiple security domains.

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Information Operations Command and Control Dynamic Network Defense (IOC^2 DND) Experiment Research Findings

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ABSTRACT
The Information Operations Command and Control Dynamic Network Defense (IOC^2 DND) experiment was designed to assess the ability to defend a computer network dynamically using the Embedded Firewall (EFW) network interface system, and to measure the impact on a warfighter's workload, situational awareness, and command and control capabilities. SSC San Diego's Information Operations Center of the Future provided a highly authentic shipboard joint operations center environment and task scenario, defending against simulated hacker attacks using a realistic network and EFW rule set experimentation. This paper discusses the IOC^2 DND experiment and its results.

INTRODUCTION

Just after the 11 September 2001 attacks, an "unemployed United Kingdom computer system administrator" broke into a U.S. Naval Weapons Station computer network, stealing computer passwords, and shutting down the network [1]. This was not an isolated event [2], and as the Navy moves aggressively toward network-centric warfare, concerns with protecting its networks have become critical.

In response to the increasing threats and risk associated with Department of Defense (DoD) computer networks, the Joint Chiefs of Staff issued a memo (CJCS Memo CM-510-99 dated 10 Mar 99) that offered specific guidance for protecting networks against threats or actual attacks. That memo identified five levels of information operations conditions (INFOCONs) that progressively protected Navy computer networks. Research to assess their efficacy [3] was conducted and determined that INFOCONs did protect networks, but with proportional loss of network capability. A more "surgical" method of network defense was required, and the current research was designed to address that need using the Embedded Firewall (EFW) concept [4, 5].

EXPERIMENT DESIGN

SSC San Diego's Information Operations Center of the Future (IOCOF) conducted the Information Operations Command and Control Dynamic Network Defense (IOC2 DND) Experiment over 3 days in November 2002.[1] The objective of the experiment was to assess dynamic network defense, using EFW, while measuring the impact on a warfighter's workload, situational awareness, and command and control capabilities. EFW is a Defense Advanced Research Projects Agency (DARPA)-developed solution commercialized by 3Com® that adds a layer of protection across the network via a policy[2] server and network interface cards. In contrast to the traditional INFOCON approach to network security, the EFW option allows centralized firewall management and dynamic response, tailoring defense by individual server, workstation, or laptop.

[1] Experiment sponsors included OPNAV N64, Navy Warfare Development Command (NWDC), Defense Advanced Research Projects Agency (DARPA), Space and Naval Warfare Systems Command (SPAWAR) PMW-161, and SPAWAR PMW-189.

[2] The word "policy" in this context refers to an EFW rule set and has no implications for organizational policy.

The IOCOF provided a highly authentic replication of a shipboard joint operations center (JOC), patterned after the JOC aboard USS *Coronado* (AGF 11), the Third Fleet's Flagship. The JOC included such systems as Global Command and Control System–Maritime (GCCS–M) and Information Technology for the 21st Century (IT-21) workstations. Additionally, the IOCOF incorporated a broader test bed to conduct detailed technical analysis.

During Phase I, the SSC San Diego Red (network attack) and Blue (network defense) teams worked collectively to identify the ideal combination of EFW rule sets and policies to enable a Joint Task Force (JTF) to operate during network attacks on a simulated afloat mission.

During Phase II, volunteer Commander Third Fleet (C3F) participants manned the IOCOF as a JOC for five 4-hour watches over 3 days. The watches provided a backdrop to assess the impact of EFW policies in an operational environment. Working against a realistic naval scenario and interacting with the IOCOF White Cell, JOC watchstanders performed roles typical of those experienced during JTF operations afloat. The focus of this effort was to develop tactics, techniques, and procedures to aid EFW transition into the Fleet. Experiment personnel accumulated over a gigabyte of electronic data during each watch and gathered metrics from participant observations and surveys.

WATCHES

Although the scenario theme was consistent across the five watches, each watch was distinct in that the specific tasks and resources differed. In addition, the five watches incorporated five different EFW conditions, as follows:

- Watch 1 – Baseline EFW policy. During Phase I, this rule set was determined to provide maximal network protection while assuring no expected impact to warfighters.
- Watch 2 – Baseline EFW policy plus client file sharing blocked (same policy in effect for entire watch). This is considered an optimal "hardened" policy, again having minimal impact.
- Watch 3 – A denial of service (DoS) exploit was initiated and then compounded by denying access to the backup domain controller (simulating pushing the wrong anti-DoS rule set). Later, the correct rule set was "pushed," with full service restored to all systems in the second half.
- Watch 4 – Started with the baseline hardened EFW policy, and then approximately half-way into the watch the selective minimize policy was initiated.
- Watch 5 – Started with the baseline hardened EFW policy, and then approximately 30 minutes into the watch all chat was blocked.

RESEARCH PARTICIPANTS

The experiment's nine participants consisted of six Navy officers and three chief petty officers with 166 years of combined military service. The average age was 38.8 years, and their mean years of service was 18.4. The participants served in the simulated JOC as a Combined Joint Task Force (CJTF) team during the 3 days of simulated operations. Research data were collected and analyzed from the participants.

METRICS

Workload was measured using the National Aeronautics and Space Administration (NASA) Task Load Index, a standardized form addressing level-of-effort topics [6]. On the same form, research participants were asked to provide their estimates of (1) situational awareness (SA), (2) task-related command and control capability, and (3) supporting team's computer network availability, all using a 10-point scale that ranged from 1 (poor) to 10 (outstanding). In addition, because it is critical to practically all military experiments and exercises, SA [7] was assessed during each watch using the Situation Awareness Rating Technique (SART). SART assesses each respondent's task-related demand (cognitive demand), supply (resources), and understanding, which combined mathematically yields an index of SA such that when demand exceeds supply, there is a negative effect on understanding, leading to an overall reduction in SA. Thus, two different estimates of SA were obtained during each watch, namely a subjective measure (1 to 10) on the NASA Task Load Index form, and the SART. One other metric was obtained from each participant: the amount of time it would take to complete his or her task at the end of that watch. The reasoning was that under typical conditions, when SA was high, and networks were normal, JOC participants could generally maintain task requirements and remain "ahead of the curve." However, when SA was reduced and/or networks were degraded, the workload demand would require increased time to complete assigned tasking.

DATA ANALYSIS

The data were collected during the five watches; all findings reported here are stated as descriptive statistics, without inferential statistical implications. To obtain a better comparison among these various data, each having different means and variance metrics, the metrics were converted to McCall's T-scores [8] to facilitate their comparison across measures and within watches (W); the data are shown in Table 1. The T-score is standardized, having a mean of 50 and a standard deviation of 10, thus allowing comparison across different impact indices.

These data clearly show that during Watches 1 and 2, when the baseline and enhanced baseline EFW policies were in effect, participants reported few or no adverse effects in either workload or for the various measures of SA. That finding holds also for the participants' estimates of command

TABLE 1. Standardized (T-scores) operational capability measures.

	Day 1	Day 2			Day 3		
	W1	W2	W3 Early	W3 Late	W4	W5	
Dependent Variables	Baseline EFW	Baseline EFW +	DOS	Baseline EFW	Minimized	Chat Blocked	Mean
Workload	46.9	46.4	70.3	44.5	44.8	47.1	50.0
SA: (1–10)	48.9	54.5	30.5	57.2	56.1	52.8	50.0
SA: SART	51.2	57.2	30.7	56.7	55.3	48.8	50.0
C^2 Capability	51.1	52.5	30.2	57.6	55.7	52.9	50.0
Increased Time	44.4	43.1	68.8	42.5	48.3	53.0	50.0

and control (C^2) capability. Moreover, SA increased slightly in Watch 2, consistent with the powerful group "learning effect" noted in the first IOC^2 experiment [3].

Perhaps the most striking finding during this phase of the experiment occurred early on the second day, during Watch 3, when a simulated DoS attack occurred and the EFW DoS policy was initiated early in the watch and enforced for approximately 70 minutes. After that, the DoS policy was removed, and the baseline EFW policy was instituted. The data in Table 1 show the impact to the participants of the EFW policy in effect during the first half of Watch 3. Workload increased, and all measures of SA declined precipitously, as did the participants' estimates of their C^2 capability.

Similarly, the participants' estimated increased time to complete their tasks rose to the highest level in the experiment, approximately a nineteen-fold increase over baseline measures.[3] Although not shown, and perhaps consistent with expectations, it is interesting to note that the various measures of phone use increased during this time, approximately three-fold for all measures.

These data clearly show the two standard deviation declines in all measures of SA and C^2 capability, as well as the equally substantial increases to workload and estimates of increased time during the early part of Watch 3. Any data shifts that approximate two standard deviations must be considered important. Note also that all measures in Table 1 returned to their approximate baseline levels during the second half of Watch 3. The SA and workload T-score data are shown graphically for all five watches in Figure 1.

In general, modifications to the network using EFW in response to mission requirements were accomplished easily and quickly from the EFW policy server. Additionally, laboratory EFW implementation on operational networks resulted in numerous lessons learned to assist in fleet transition and employment.

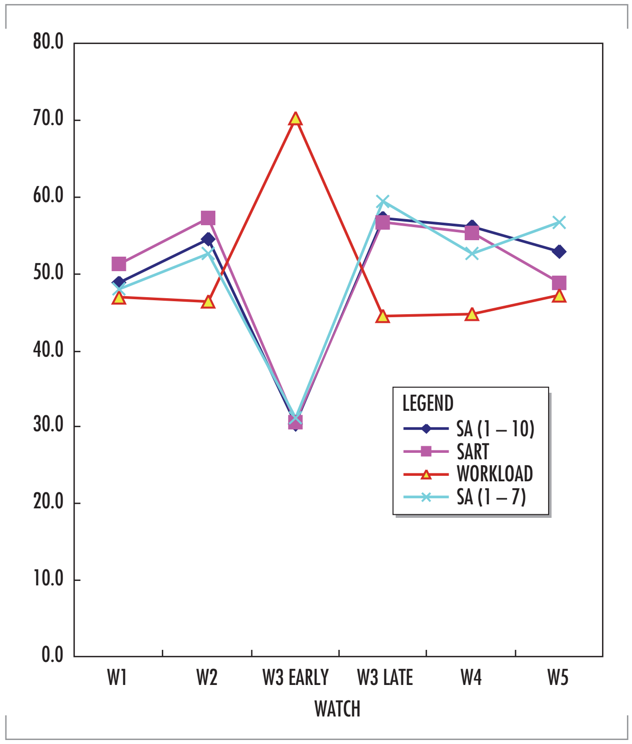

FIGURE 1. Standardized impact measures: situation awareness and workload.

CONCLUSIONS

To protect networks, some services and ports must be restricted, yet the extent of restriction required empirical research and analysis. Based on this research we conclude that:

- The data in Table 1 and Figure 1 indicate that the EFW policies chosen for this experiment, with one exception, likely will not pose negative impact for operational warfighters.
- EFW rule sets were effective, with little or no disruption to the operators.
- The EFW proved beneficial in managing and reallocating bandwidth and enforcing operations security.
- Dynamic network defense, using EFW, allowed immediate, surgical, concrete responses to network threats.

Finally, one participant's post-experiment comment indicates the overall value of the IOC2 DND experiment:

"This experiment was critical to C3F watchstanders and afforded us the ability to run a full CJTF scenario exercise while our computer networks were undergoing attacks. This controlled environment afforded us the ability to experience what it would be like to conduct operations in a hostile network environment. We would not have been able to do this at sea."

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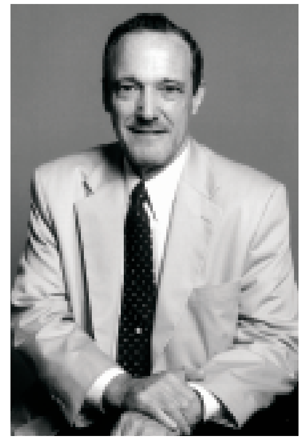

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The Process for Conducting Operational Risk Assessments on C4ISR Technologies

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ABSTRACT

This paper describes a process that mitigates the risk associated with the acquisition and fielding of command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) technologies to the Fleet. By leveraging warfighter input early and working with the technology developer to identify critical operational issues and define measurement standards, the process assists in the speed and efficiency at which a technology is fielded.

INTRODUCTION

The process for conducting operational risk assessments described here was developed in response to a bona fide requirement to mitigate the risk associated with the acquisition and fielding of C4ISR technologies that undergo rapid rates of advancement. The process[1] provides critical operational information for technology developers and assists in the speed and efficiency at which a technology is fielded by leveraging Fleet and Marine warfighter input and collaborating with the technology developer to identify critical operational issues and define measurement standards (i.e., measures of effectiveness, suitability, and performance).

The process was developed with the support of Operational Test and Evaluation Force (OPTEVFOR) and is designed to complement their operational assessment and evaluation processes. Test plans and reports produced during the process are designed to match those of OPTEVFOR to maintain continuity if and when a technology transitions to a program of record. The documentation of critical operational issues, measures of effectiveness, measures of suitability, test plans, and reports can assist an OPTEVFOR-conducted operational evaluation and, ultimately, the speed at which even large, program of record technologies are fielded.

A fundamental aspect of the process is the early and continuous involvement of the warfighter with the technology developer, sponsor, and other stakeholders. Through this teaming, technologies can effectively be fielded with as much risk mitigated as possible, and can positively influence speed to capability. This process was primarily developed to be used during operational testing and acquisition, but the fundamentals can be applied to assessments conducted during developmental testing. The process has two sub-processes, very early and early operational risk assessments (VEORA and EORA) that can be conducted during the concept development phase of both evolutionary acquisition models. Figure 1 shows the evolutionary acquisition process as described by the traditional incremental developmental model and the spiral development model as derived from DoD Directive 5000.1 [1] and DoD Instruction 5000.2 [2] of 12 May 2003. Throughout spiral development, OPTEVFOR will operate more dynamically ad assess the risks associated with each increment.[3]

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[1] For simplicity, the process for conducting operational risk assessments on command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) technologies will be referred to in this paper as "the process."

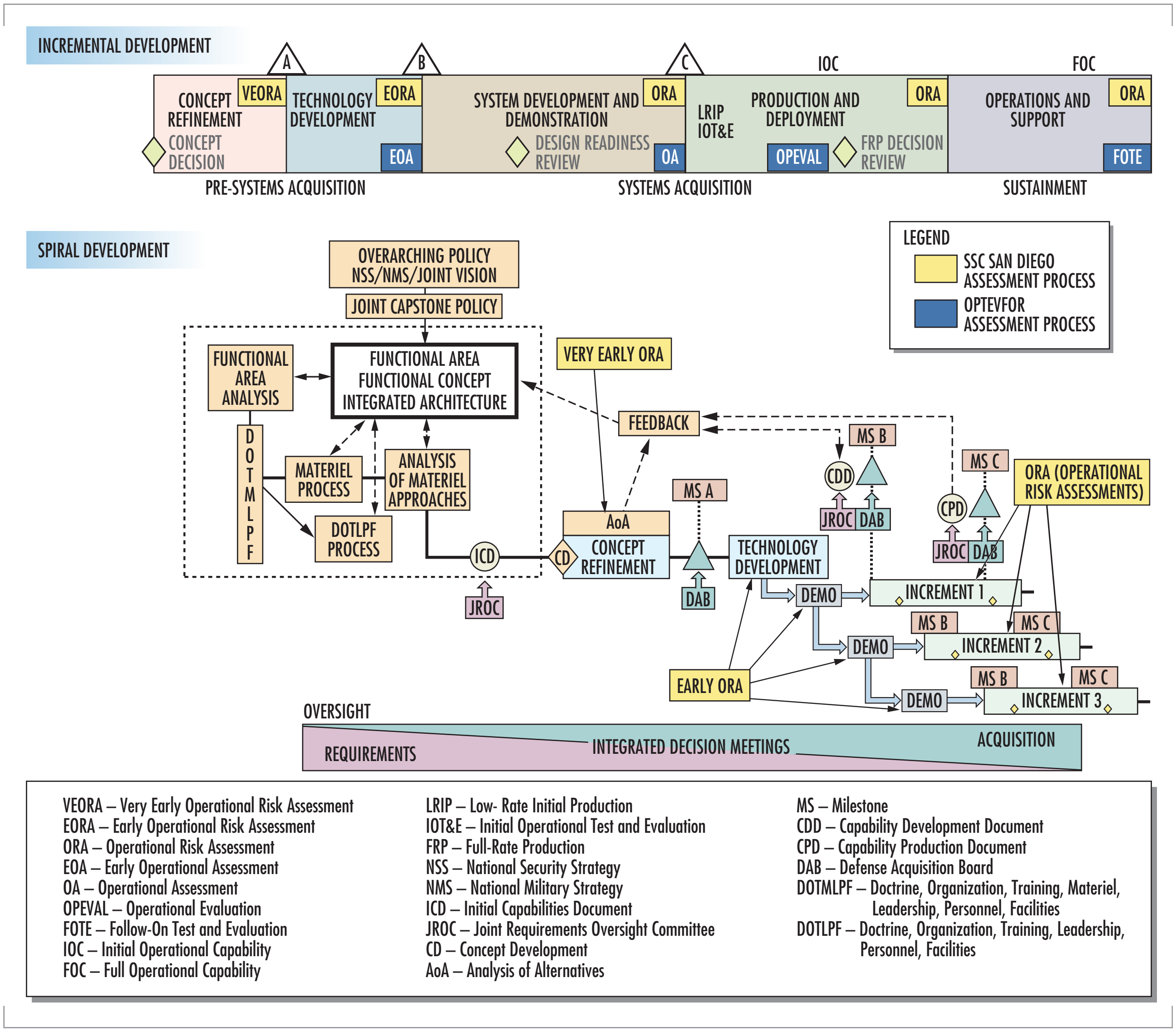

FIGURE 1. The evolutionary acquisition process.

OPTEVFOR

Statute dictates that in each of the services only one independent command will have the charter to conduct assessments prior to fielding an acquisition; thus, the process was developed with the aid and support of OPTEVFOR. Additionally, OPTEVFOR has been conducting operational assessment for 50 years; thus, it made sense to seek guidance and work collaboratively with OPTEVFOR in the development of the process. The process is intended to complement OPTEVFOR's assessment process, not replace or compete with it. This is partially accomplished by creating test plans and reports that have the same look and feel as those of OPTEVFOR's. The metrics section explains this in further detail.

CRITICAL OPERATIONAL ISSUES

Critical operational issues are key to ensuring that an assessment focuses on what is important to the warfighter. Critical operational issues are presented in the form of a question, and are answered by process metrics. The process identifies critical operational issues through a collaborative effort in one or more planned sessions. The technique used involves a subject-matter expert briefing a group of selected individuals while they input their responses into a computer-based collaborative tool. In the near future, this part of the process will be almost entirely web-based. The tool allows for simultaneous but anonymous input and ensures that all data and participant comments are collected and archived. By allowing simultaneous input during a brief, a subject-matter expert can answer questions and clarify functionality as to a technology's capabilities and limitations. Anonymity allows for a broad spectrum of personnel to work collaboratively without rank, position, or seniority being a factor. For example, a group consisting of a junior officer, a senior enlisted person, a systems engineer, and a field technician can provide input without the influence of any disparity in rank or pay grades. At the conclusion of each session, the group votes to determine the most important issues. The output is collected and forms the basis of the metrics to be used.

METRICS

Assessments, of any type, must have a method of measuring the outcome of a test. Test objectives are obtained by the collaborative development of measures of effectiveness, measures of suitability, and/or measures of performance. With the exception of measures of performance, these are defined and developed in the same way as OPTEVFOR.

Measures of effectiveness are developed based on how well a technology is designed to perform in its intended environment, with as many operational aspects taken into consideration as possible. For example, if a technology's mission is to provide area surveillance, then a test to determine its effectiveness would be to install it where it is expected to be fielded, with consideration as to what might diminish its capabilities, such as the environment, expected threat, and countermeasures.

Measures of suitability are defined as the capability of a technology, when operated by warfighters, to perform as expected. Measures of suitability have been categorized by OPTEVFOR and are referred to as suitability tests. Suitability test categories are intuitive and guide the test developers in placing the warfighter's issues in the categories listed below:

S-1 Reliability	S-2 Maintainability
S-3 Availability	S-4 Logistical Supportability
S-5 Compatibility	S-6 Interoperability
S-7 Training	S-8 Human Factors
S-9 Safety	S-10 Documentation

At the completion of the collection of critical operational issues, it is determined whether a measure of effectiveness or a measure of suitability will be best suited to satisfy a particular critical operational issue.

Normally, measures of performance are not used by OPTEVFOR in their assessment processes. However, as defined in the context of this process, measures of performance are a viable metric. Additionally, other

organizations in the test and evaluation community define and use measures of performance. The process defines measures of performance as to how well a technology functions in relation to a previous version or release. They are used to effectively measure the differences in engineering and technological changes from the warfighter's perspective. This can be a positive or negative change in performance, but as with any other measure, must not be weighed alone.

For a more detailed explanation of OPTEVFOR processes, procedures, and terminology, refer to [1].

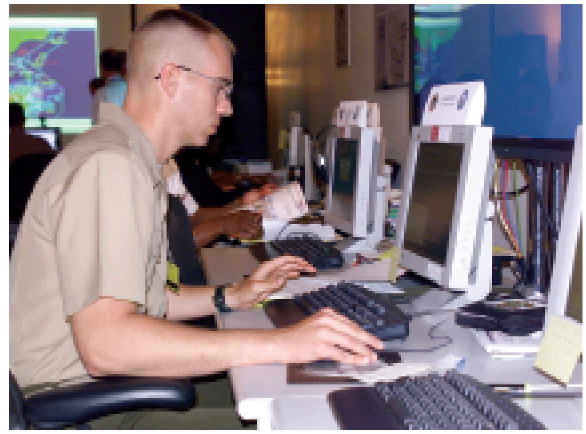

FIGURE 2. Warfighter performing operational risk assessment.

TEST EXECUTION

A test plan is produced with metrics designed to satisfy the identified critical operational issues, i.e., the tests answer the questions raised by the operational issues. The test plan will also include the schedule of events, identification of the assessors, any security issues, and a scenario where necessary. A dry run is conducted for a final shakeout and, within the constraints of the schedule, the subject-matter expert will determine that the technology is ready to test. The technology is then given to the warfighter (Figure 2). Testing is best conducted in two 3-hour sessions each day of the assessment. An assessment should take place over a 2- to 5-day period, depending on the complexity of the technology and the number of identified critical operational issues. Back-up sessions can be scheduled due to operational issues, and follow-on sessions can be scheduled if other serious issues are identified during the primary assessment.

DATA COLLECTION AND ANALYSIS

Data sets are collected using a government-owned, web-based tool, the Joint Battle Center's Data Collection and Analysis Tool (JDCAT). JDCAT is used for data collection, analysis, and as an aid in the development of the final report. Analysis is performed by mapping critical operational issues to metrics, then directly to the warfighter evaluation. The captured data sets are irrefutable. Each response from the warfighter correlates to a collaboratively developed and agreed-upon critical operational issue that maps directly to the chosen measurement of effectiveness, suitability, or performance.

FINAL REPORT

The final report is a culmination of the identified critical operational issues, metrics, test plan, layout, outcome, procedures used, and summary. The final report may include a recommendation by the facilitators of the assessment (this will be determined before the process starts). The final report is designed to look and feel similar to reports produced by OPTEVFOR. Thus, if and when a technology becomes a program of record and comes under the auspices of OPTEVOR, the report will aid the operational test director in determining on what areas and functionalities an operational evaluation must focus.

CONCLUSION

Although this process was developed with Navy and Marine warfighters in mind, its fundamentals and concepts can apply to all branches of service as well as our North Atlantic Treaty Organization (NATO) and coalition partners. In our current joint and coalition environment, our goal is to involve as many organizations as possible for not only adoption of this process, but for participation in collaborative sessions. This is becoming more of a possibility because of web-enabled tools, multi-national networks, and language translators.

ACKNOWLEDGMENTS

The process discussed in this paper has evolved over a number of years with the help of many individuals and organizations. Mention and gratitude must be made to the warfighters, civilians, and contract support of the Space and Naval Warfare Systems Command's Operational Experiments/Sea Trial Division, SSC San Diego's Special Projects and Implementations Branch, and Commander, Operational Test and Evaluation Force Headquarters and Pacific Detachment.

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Database Cluster Hierarchies and Semantic Relationship Discovery in Distributed Database Systems

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ABSTRACT

The advent of the Homeland Defense initiative has brought with it a renewed sense of importance of database management technologies. Database cluster hierarchies, based on the affinity relationships of databases, allow users to incrementally and dynamically access needed information. In this study, a new data-mining framework is presented. The framework employs database clusters to discover novel semantic relationships in the object classes in distinct databases. The approach uses object-oriented, association rule mining, and logical (fuzzy) reasoning techniques to bridge heterogeneity in large-scale heterogeneous database environments.

INTRODUCTION

Given the increasing complexity of real-world applications, the need to access a collection of cooperating but autonomous distributed databases becomes inevitable. In such a federated database system, which consists of a collection of databases and related access methods, semantically related data might be represented in different database schemas under *diverse database management systems (DBMSs)*. The quantity of data is increasing with no end in sight, and it has been estimated that the amount of data stored in the world's databases doubles every 20 months [1]. Inexpensive, multi-gigabyte disks and other storage devices allow us to save much data. However, our ability to interpret and analyze the data is still limited. Thus, *data mining* is relegated as one of the few paths for elucidating patterns from the data [2]. Nevertheless, the great quantity of data makes the discovery process computationally expensive. It is desirable to effect the knowledge discovery process on a relatively constrained subset of data to reduce the computational complexity. Here, *domain knowledge* can be used to reduce the rank of the data being considered to limit the search for patterns [3]. It is well known that the user in the loop has some previous concepts or knowledge about the domain represented by the database.

Domain knowledge is predicated upon domain representation. A proper representation enables the extraction of features for use in data mining. It is necessary that the feature space be randomized [4]—for example, in the form of an algorithm—to offset representational complexity. However, in many domains of military interest—including battle management and command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR)—full algorithmic definitions are not known. The discovery of latent semantic knowledge in heterogeneous federated databases provides a viable alternative.

In this study, a framework is presented consisting of database cluster hierarchies [5] and semantic relationship discovery [3 and 6] by using object-oriented, associative mining, and logical (fuzzy) reasoning techniques to effectively fuse a large-scale federated database system. Users can incrementally and dynamically access the pieces of information they

want without being overwhelmed with all of the unstructured information. The proposed framework provides a flexible means for sharing information across multiple databases.

DATABASE CLUSTER HIERARCHY

Let, $Q=\{q_1, q_2,...,q_q\}$ contain all the queries issued to $D=\{d_1, d_2,...,d_d\}$ databases in a period of time. Let **M** be a symmetric matrix of size $g \times g$ indicating the affinity measures of the databases in a partition that contains g databases ($g \leq |D|$). Our proposed method [5] takes the training data as input, computes the entities of the matrix **M**, calculates the distance difference values, permutes its columns, and then generates an updated matrix $\mathbf{M}'$. The permutation is performed by considering the minimum of the distance difference values for columns i and j. Let column i be the one that needs to be placed in the temporary matrix **O** that consists of the first several columns of **M**. Column i can be placed on the left or right of column j in **O**. The main idea is that, given relative stability in the domain set, Q, position column i in the place that satisfies two conditions: its affinity measure should be less than or equal to the affinity measure of its left neighbor and greater than or equal to the affinity measure of its right neighbor. Simply consider one of these two conditions for the leftmost or the rightmost position of **O** because it has only one neighbor here. The mean value of the first column is chosen to be the splitting criterion, since the first column tends to have the larger affinity value. Two clusters can thus be iteratively generated until some predefined conditions are met.

SEMANTIC RELATIONSHIP DISCOVERY

A data-mining approach consisting of association rule mining and logical reasoning is proposed to exploit new semantic relationships among object classes in the databases for each cluster. Clearly, discovering new semantic relationships for object classes across multiple databases will not only serve to facilitate schema integration but will also speed up query processing.

Generalized Association-Rule-Mining Method

Figure 1 depicts the architecture of the generalized association-mining algorithm where domain knowledge has been incorporated [3]. The idea is to use domain knowledge to eliminate unnecessary computational efforts in Phase I by reducing the rank of the data in the computation tasks.

To evaluate the performance of the experiments, five real databases were employed, representing 22 object classes, accessed by 17,222 queries. The total number of operative reductions exceeded 20,005,000, which represented a significant savings. Several experiments were conducted by varying the number of databases, object classes, or queries to make the performance analysis more general. The number of operations in one particular step in the first phase was compared with and without the domain knowledge, as shown in

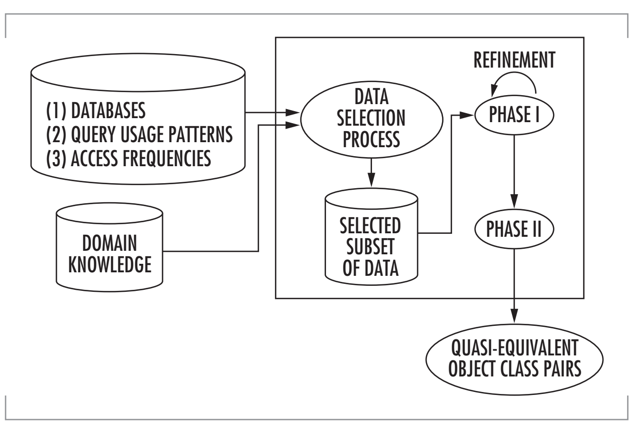

FIGURE 1. Architecture for generalized association rule mining with domain knowledge.

Figure 2(A, B, and C). The fewer the operations, the better would be the performance.

It can be gleaned from Figure 2 that the number of operations was significantly reduced under all of the experiments. In Figure 2(A), the number of operations required, without domain knowledge, using various numbers of databases, did not change. This followed because the calculation was based on the number of object classes and queries, which were fixed. Using domain knowledge, the variations in the number of operative reductions was small when the number of databases was greater than 50. However, when the number of databases was less than 50, the fewer the number of databases, the larger the number of operative reductions. This reduction can be explained by the ratio, |Q|/|D|. That is, more queries were needed to partially order the larger databases. Figure 2(B) shows that the larger the number of object classes, the larger the difference between the two algorithms. In addition, the reduction in operations grew exponentially (as can be seen from the figure). In Figure 2(C), the number of operative reductions increased as a function of the number of queries, and the increase was approximately linear.

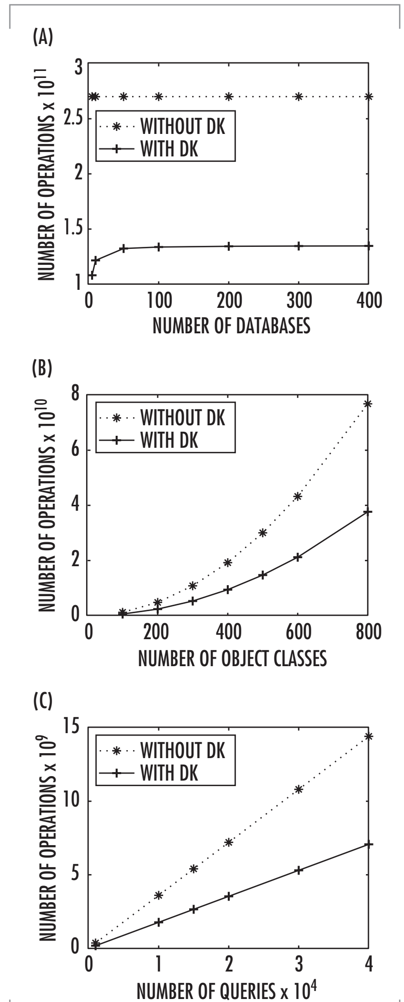

FIGURE 2. Comparison of the numbers of operations with domain knowledge (with DK) and without domain knowledge (without DK).

Logical-Based Reasoning

Here, a logical reasoning-based mechanism is presented for the inference of new semantic relationships in two databases [6].

Definition 1. $\mathbf{h}(C_{st}, C_{uv})$ is the *logical reasoning function* that derives the new semantic relationships between two object classes C_{st} and C_{uv} from different databases, where $s<u$ and $v>1$.

$$\mathbf{h}(C_{st}, C_{uv}) = CR(C_{st}, C_{u1}) \lozenge CR(C_{u1}, C_{uv}),$$

where $\lozenge$ is the logical operator ^ and is applied to each element in CR.

Definition 2. An *object class relationship* $CR(C_{st}, C_{uv})$ represents the superclass, subclass, and equivalence semantic relationships of two object classes C_{st} and C_{uv}. Its value is captured through a triplet $(\boldsymbol{P}, \boldsymbol{B}, \boldsymbol{E})$ where $\boldsymbol{P}$, $\boldsymbol{B}$, and $\boldsymbol{E}$ indicate the *su**P**erclass*, *su**B**class*, and ***E**quivalence* relations between C_{st} and C_{uv}, respectively.

Definition 3. $\mathbf{g}(C_{uv}, C_{st})$ is the *object class relationship inversion function* such that

$$CR(C_{uv}, C_{st}) = \mathbf{g}(C_{uv}, C_{st}) = (B_1, P_1, E_1) \quad \text{if } CR(C_{st}, C_{uv}) = (P_1, B_1, E_1).$$

Let S_{eq} be the object class equivalence relationship set (obtained from our generalized association-mining algorithm) and TRS_{Pk} be the total object class relation set for the cluster Pk. The proposed relationship-derivation algorithm will incrementally update TRS_{Pk} and is presented next.

For any two object classes C_{st} and C_{uv} in the databases in Pk, where $s<u$ and $v>1$ {

    if $((C_{st}, C_{uv}) \notin TRS_{Pk})$ {

        if $(\exists C_{xy}$ satisfying $(C_{st}, C_{xy}) \in S_{eq})$

            For every C_{xy}

                if $((Cxy, C_{uv}) \in TRS_{Pk})$ $CR(C_{st}, C_{uv}) = CR(C_{xy}, C_{uv})$;

                else if $(x>u \mid y>v)$ $CR(C_{st}, C_{uv}) = \mathbf{g}(C_{xy}, C_{uv})$;

        else $CR(C_{st}, C_{uv}) = \mathbf{h}(C_{st}, C_{uv})$;

        $TRS_{Pk} = TRS_{Pk} \cup (C_{st}, C_{uv})$;

    }

}

This algorithm is iteratively executed on all pairs of object classes in a cluster. The semantic relationships discovered in each cluster can be used to assist in the integration task in that cluster. In addition, this algorithm should be applied to each cluster in the database cluster hierarchy.

CONCLUSIONS

This study presents a new data-mining framework for bridging heterogeneity in large-scaled, heterogeneous, federated database systems. The proposed framework is based on database cluster hierarchy and semantic relationship discovery in multiple databases. The database cluster hierarchy provides different levels of abstractions for users to incrementally and dynamically access information. The number of platter switches for query processing can be reduced. This follows because a set of databases belonging to a certain application domain is placed in the same cluster and needs to occur in sequence on some query access path. Moreover, the constructed clusters can be used as the unit not only for query processing, but also for discovering the superclass, subclass, and equivalence relationships, which are achieved by the associative-mining and logical-reasoning methods. During this knowledge-acquisition process, some semantic conflicts can be detected and subsequently resolved through the schema integration process.

FUTURE WORK

The semantic relationship between pairs of databases is evolved through a query-driven mechanism. In particular, the symmetric matrices M^2, M^3, ..., M^r , where r is the rank of the matrix, can be used to fuzzify the semantic relations between databases m and n in terms of 2, 3, ..., r-step reachability [7]. Furthermore, the transitive closure of **M**, defined by $M_r = \bigcup_{i=1}^{r} M^i$ defines the fuzzy semantic relation between m and n for a given r, where r is taken as unity for purposes of this paper. The transitive closure of **M** allows for anticipatory cluster formation, which of course speeds access. The principle of temporal locality can be applied to remove database pairings that were not temporally co-accessed. Note that if this operation is not performed, then the system will rapidly degenerate to a single cluster, since almost every database is fuzzily related to every other. To avert this problem, define a unit time interval for time t such that the query sets $Q^{(t)}$ and $Q^{(t+1)}$ satisfy the relational constraints, $0<|Q^{(t)} \cap Q^{(t+1)}|<\min(|Q^{(t)}|,|Q^{(t+1)}|)$. The left-hand constraint ensures continuity, while the right-hand constraint ensures proper variation over time. Next, define the complement matrix, $\overline{M}$, such that the $(m, n)^{\text{th}}$ entry is 1, just in case databases m and n have *not* been accessed together during the last time interval, and otherwise 0. Then, the iterative transitive closure is defined by $M_r^{(t+1)} = M_r^{(t)} - \overline{M}_r^{(t)}$. The use of sparse matrices and distributed (server) processing ensures tractability in this approach and allows for associative cluster formation, which speeds the discovery of semantic relationships.

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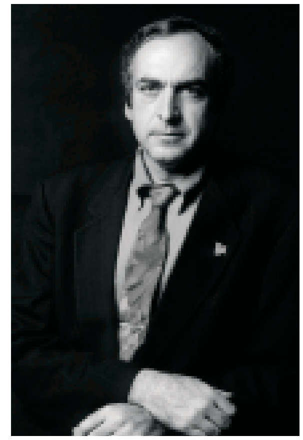

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